325 MHz coupler review

S. Kazakov

02/02/2012

Agenda

S. Kazakov:

- Coupler requirements
- Electrical coupler parameters
- Thermal coupler parameters
- Possible preliminary tests

S. Cheban:

Air cooling

O. Pronitchev:

Mechanical design of coupler

S. Kazakov

Choice of cavity /line for coupler test

Requirements

Coupler was design to feed SSR coupler family.

Maximum beam power gain per cavity in different projects:

PXIE	SSR1	~2 kW
PX ,1mA	SSR2	~3.5 kW
PX, 5mA	SSR2	~18 kW

With overhead the coupler have to work reliably at power levels:
~ 6 kW for PXIE, PX 1mA
~ 30 kW for PX 5mA

Thermal properties were calculated for power levels:
0, 3, 6, 20, 30 KW

Cryogenic losses of SSR cavities at 2K:

SSR0	~0.2W-1.5W (170W – 1300 W cryo-plant)
SSR1	~1.5W-1.8W (1300W– 1550W)
SSR2	~1.6W – 4W (1380W – 3440W)

Coupler should not be main source of cryogenic loss

SSRx cold flange can sustain power flow >1W, without quench (Serena Barbanotty simulation).

What is a maximum power can be taken by liquid He ?

Coupler has to be compatible with already designed SSR1 cavity.
(diameter of input port is fixed)

We decided to make a new coupler interchangeable with the old one
(Khabibuline-Nicol design)

20kW-30KW operation power will require antenna cooling.
Cooling must be an air type.

Possibility to apply HV bias to suppress multipactor

It has to accommodate ~1mm cavity displacement during cool down/warming up

Coupler has to be assembled with cavity in clean room

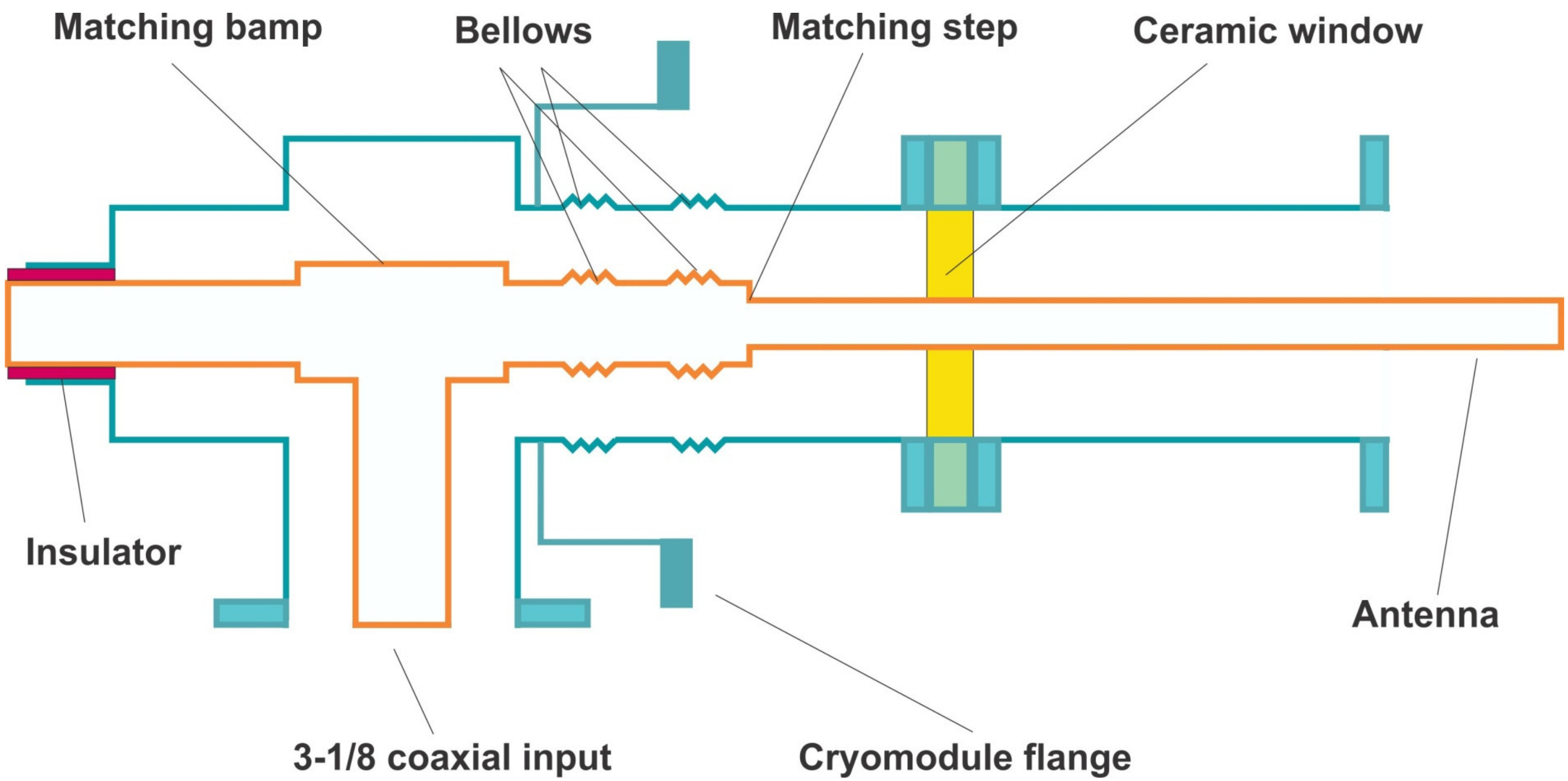
Standard coaxial input (3-1/8’’)

Design approach:

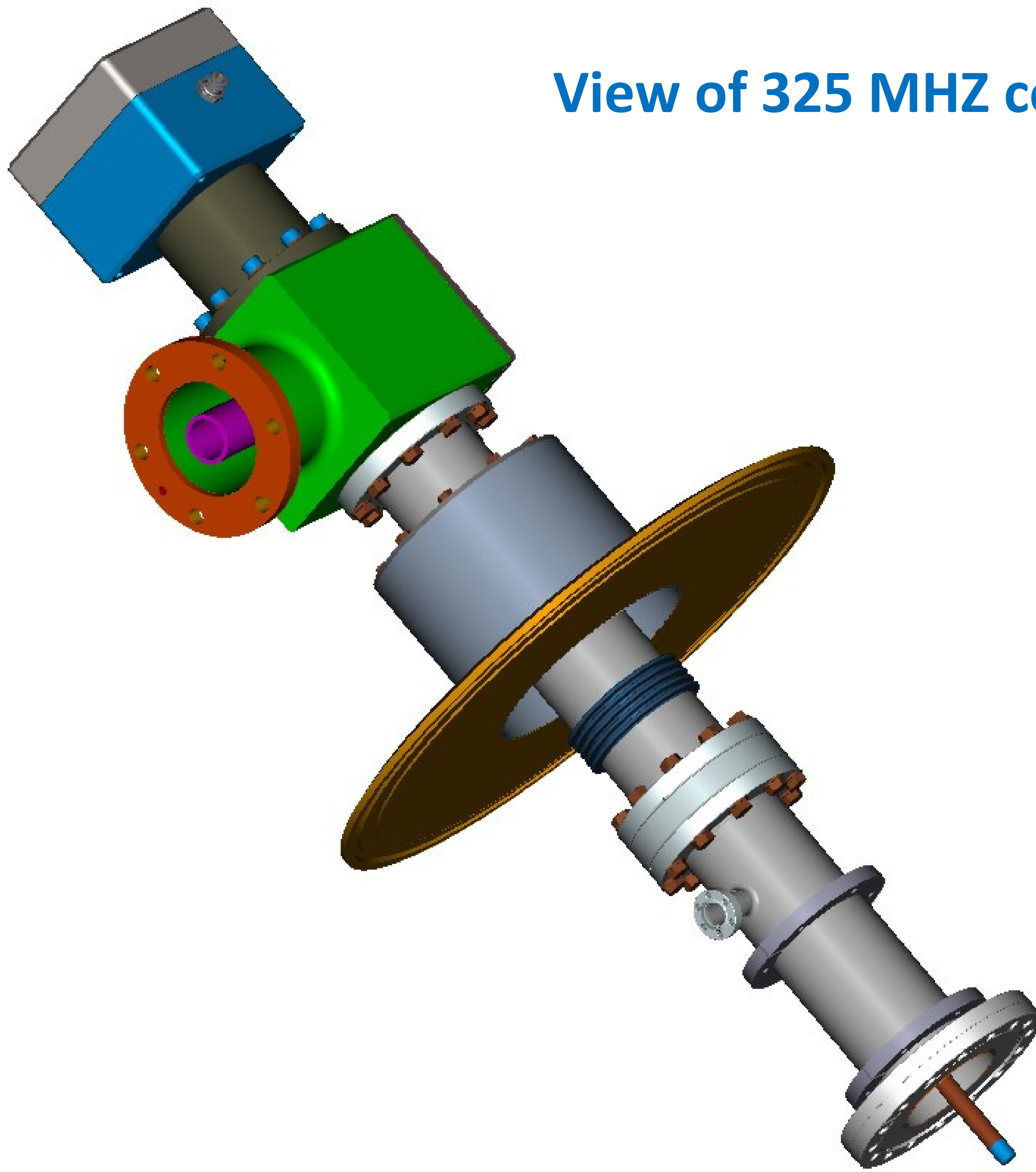
Vacuum part is simple as possible:
One window, no bellows, straight coaxial, no coating if possible.

Common technology and parts with 650 MHz coupler

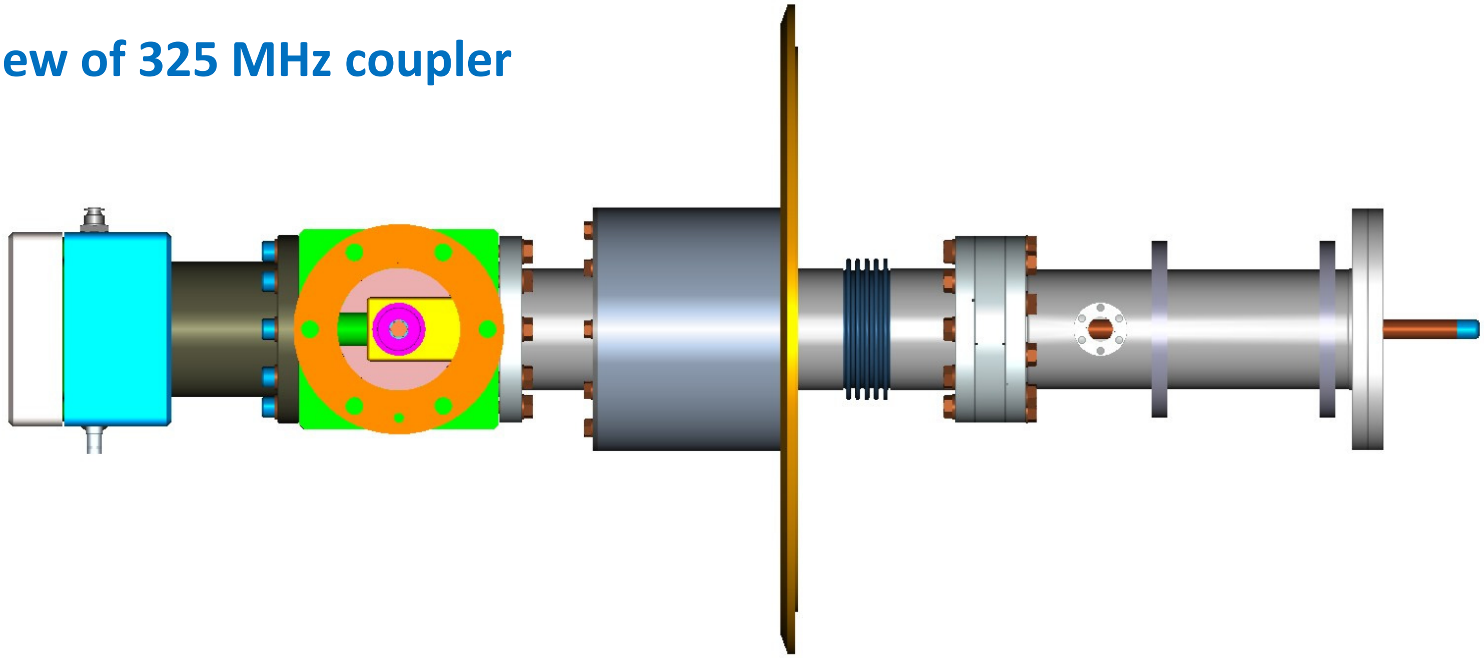
325 MHz coupler structure

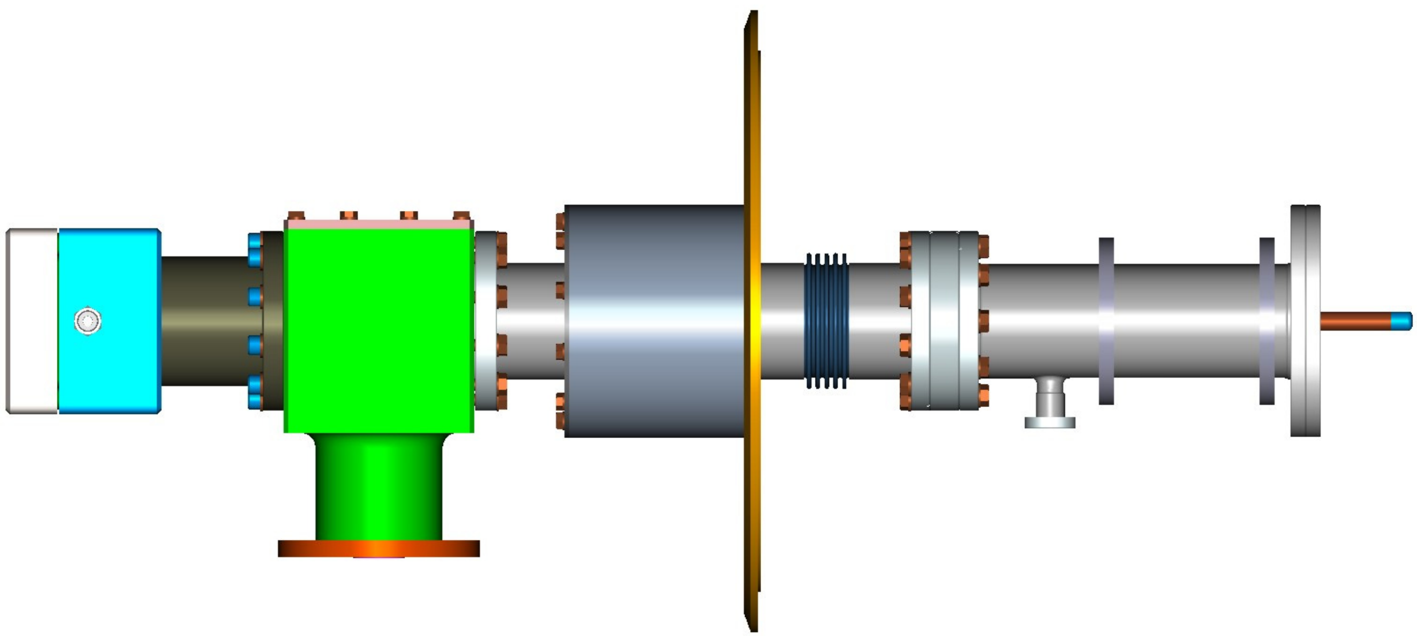


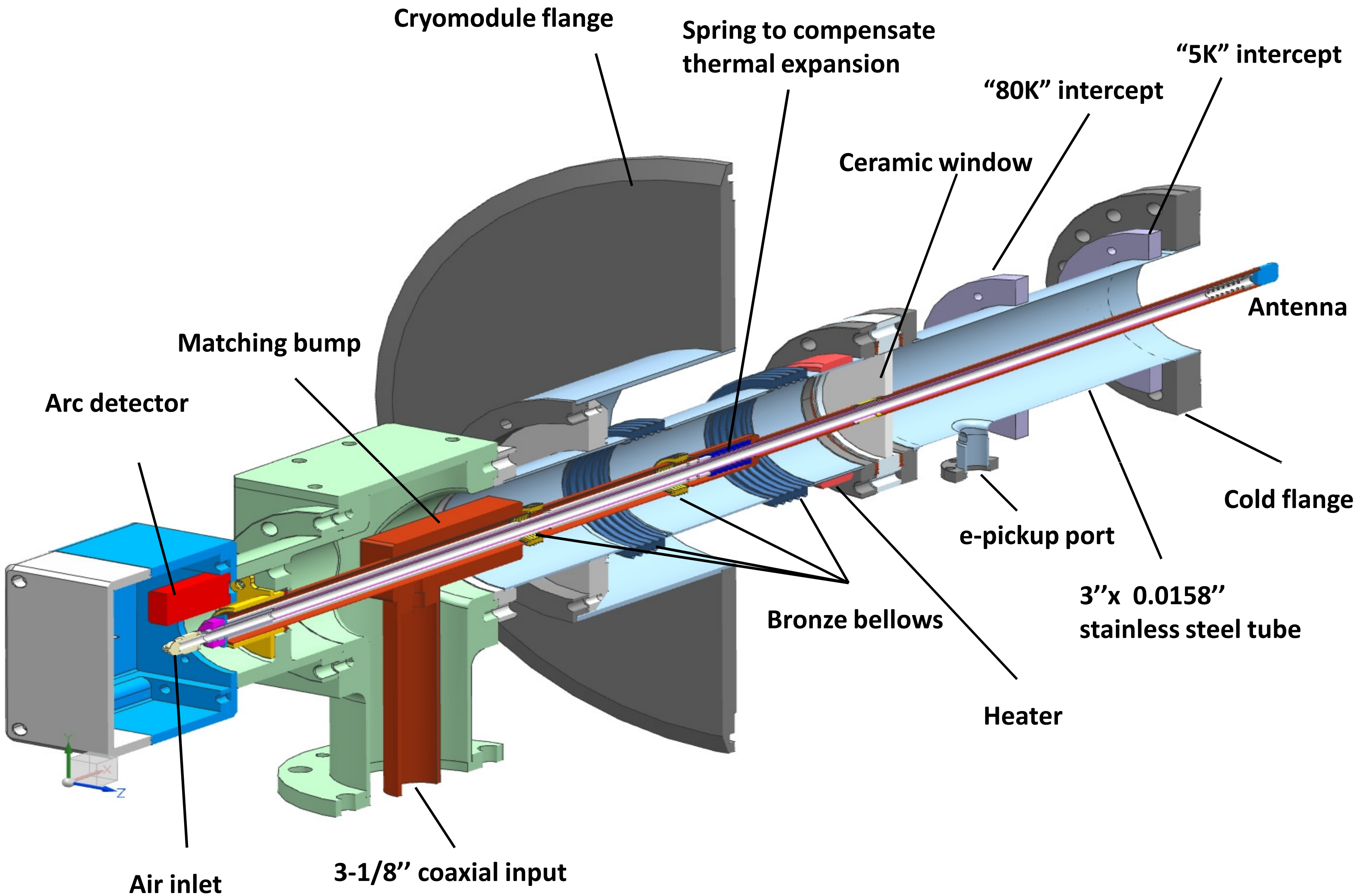
View of 325 MHZ coupler



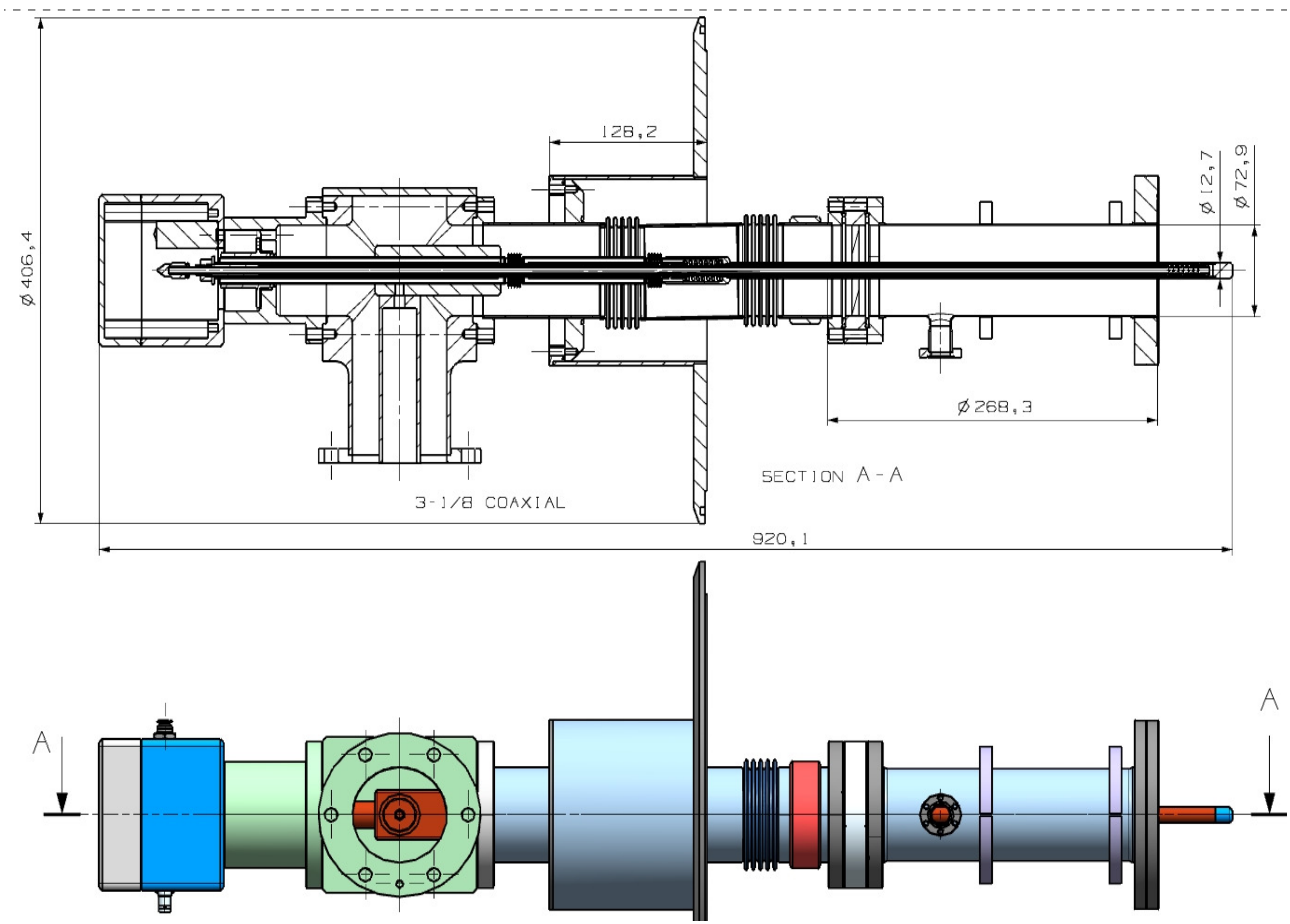
View of 325 MHz coupler





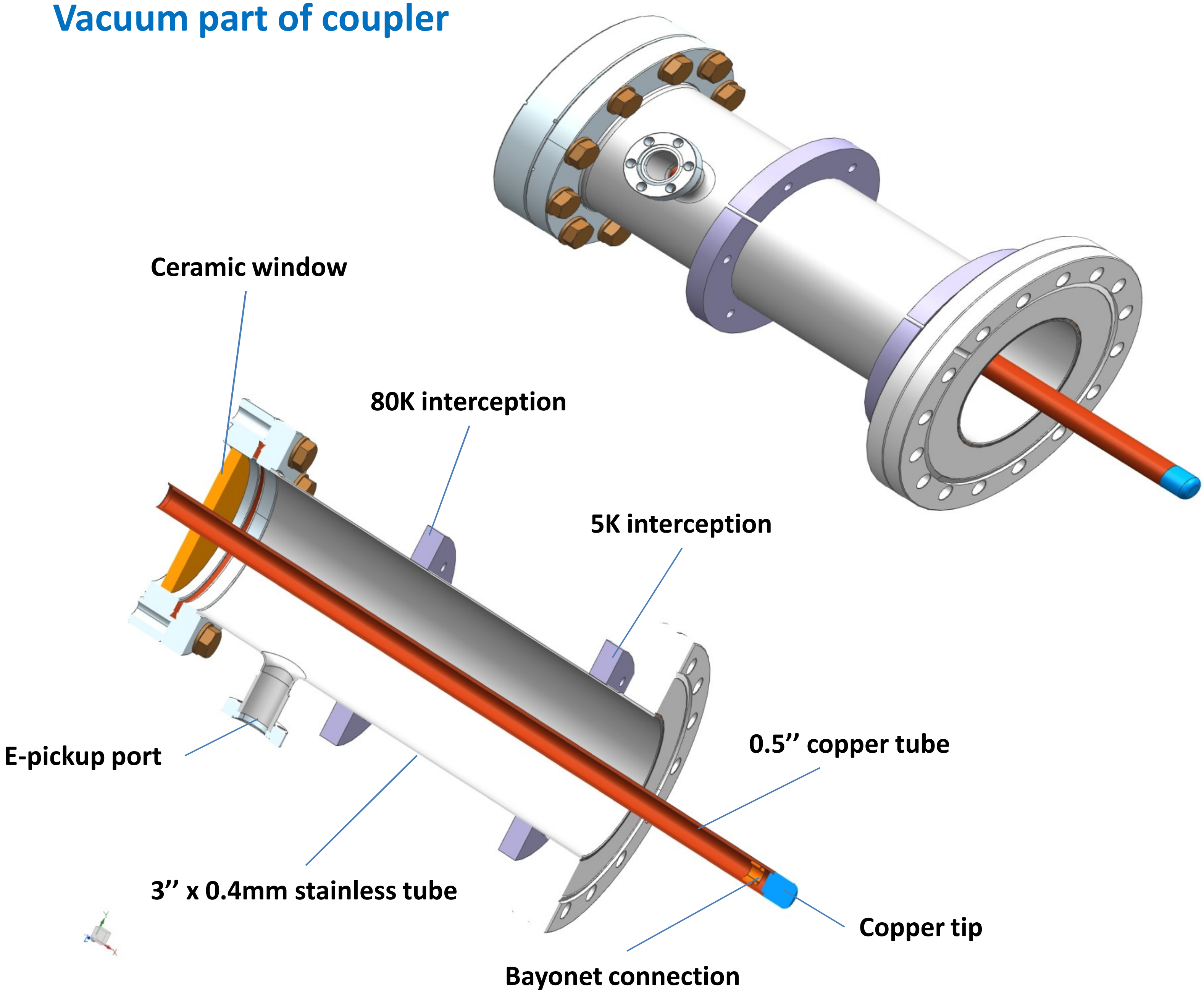

Cryomodule flange
Spring to compensate
thermal expansion
"5K" intercept
"80K" intercept
Ceramic window
Antenna
Matching bump
Arc detector
Cold flange
e-pickup port
3''x 0.0158''
stainless steel tube
Bronze bellows
Heater
Air inlet
3-1/8'' coaxial input

Main sizes of coupler



Coupler have been designed to be interchangeable with Khabibuolline-Nicol coupler

Vacuum part of coupler



Electrical parameters of 325MHz coupler

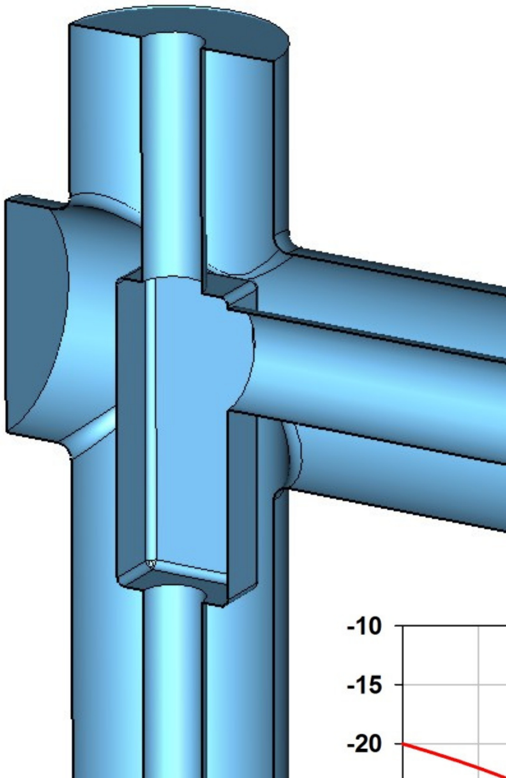
Design CW power ~ 6kW (30kW)
(30 kW - with air cooling, copper plated vacuum outer conductor)

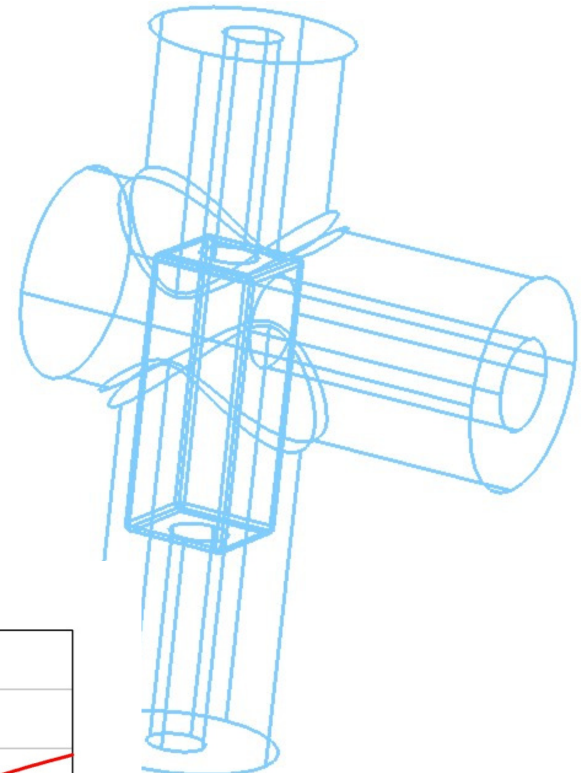
Pulse power (breakdown in air) ~ 0.4MW

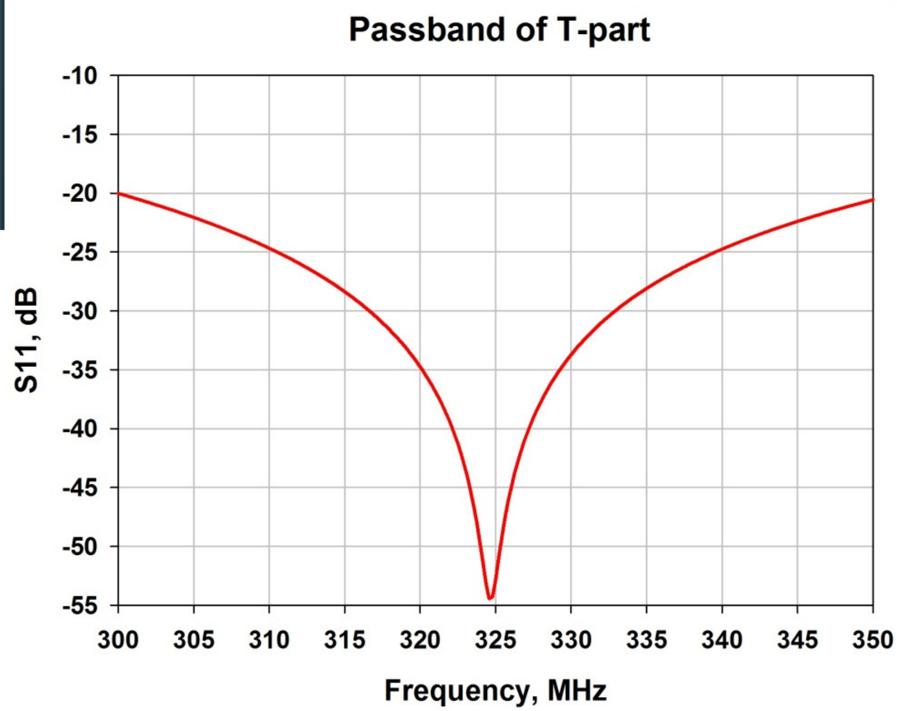
Multifactor threshold > 6 kW SW (>25kW TW)

Pass band (S11 < -20dB) ~ 50MHz, (15%)

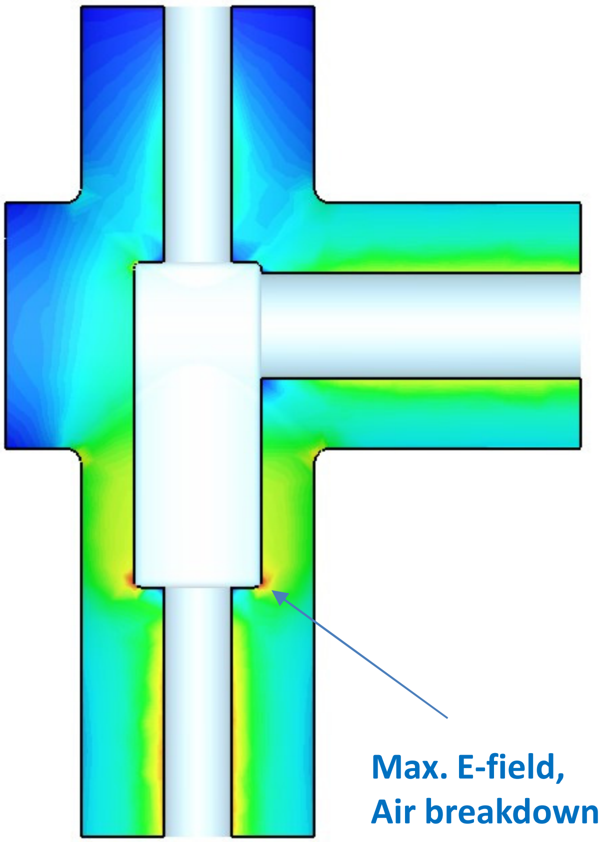
Matching section



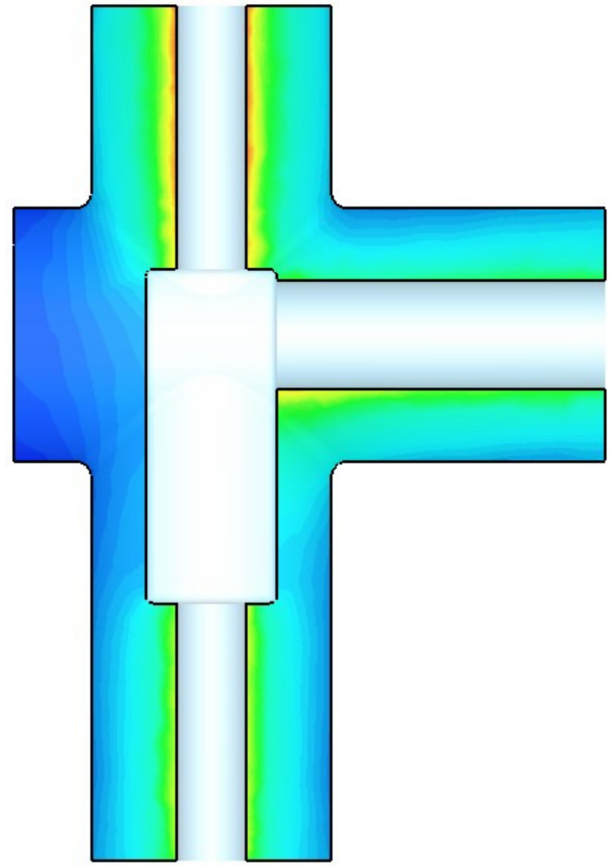




Pass band ~ 15% (-20dB)



Max. E-field,
Air breakdown limit ~ 400 kW, TW



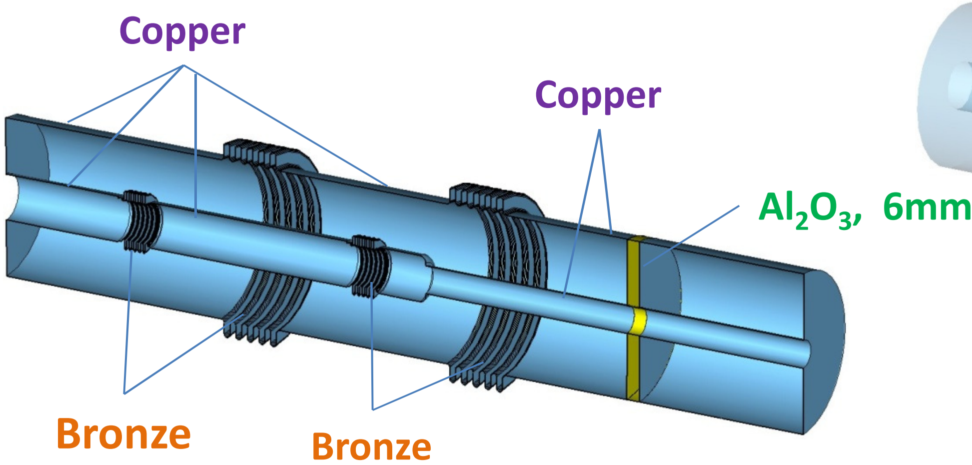
E-field

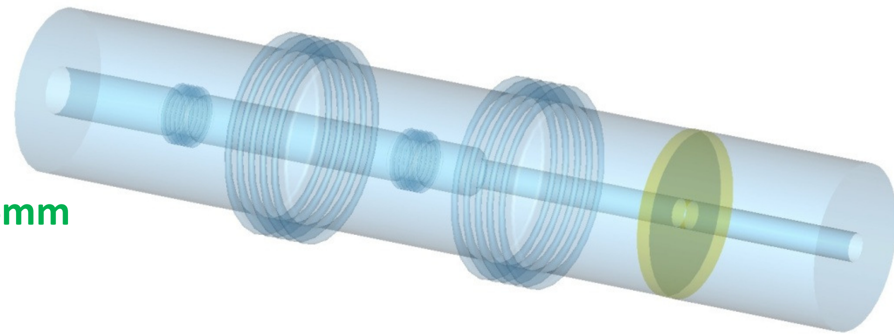
H-field

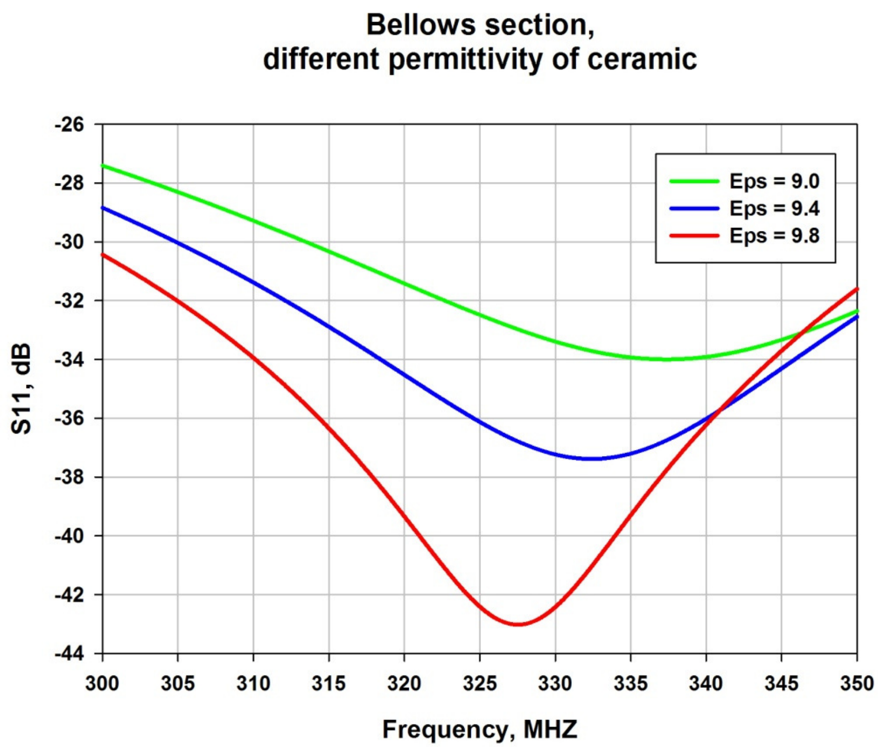
Loss (cupper) ~ 0.06%

6kW -> 3.5W, 30kW -> 18W

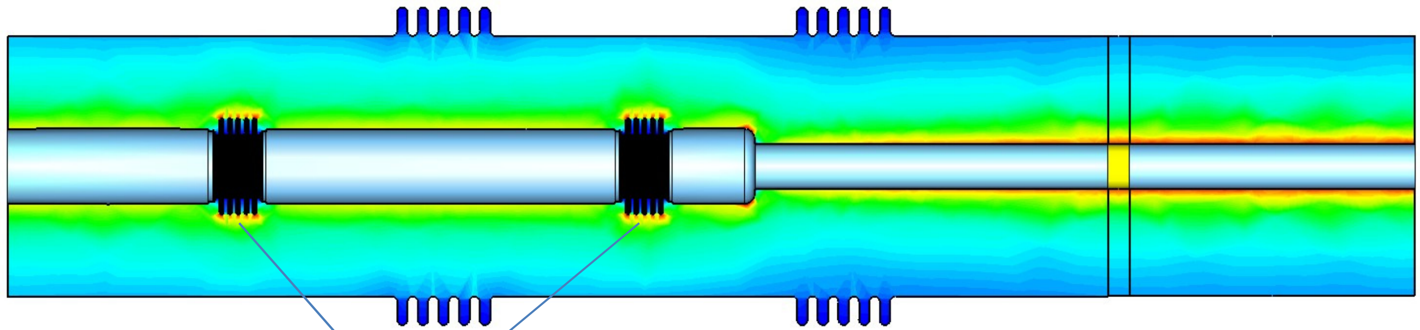
Bellow section





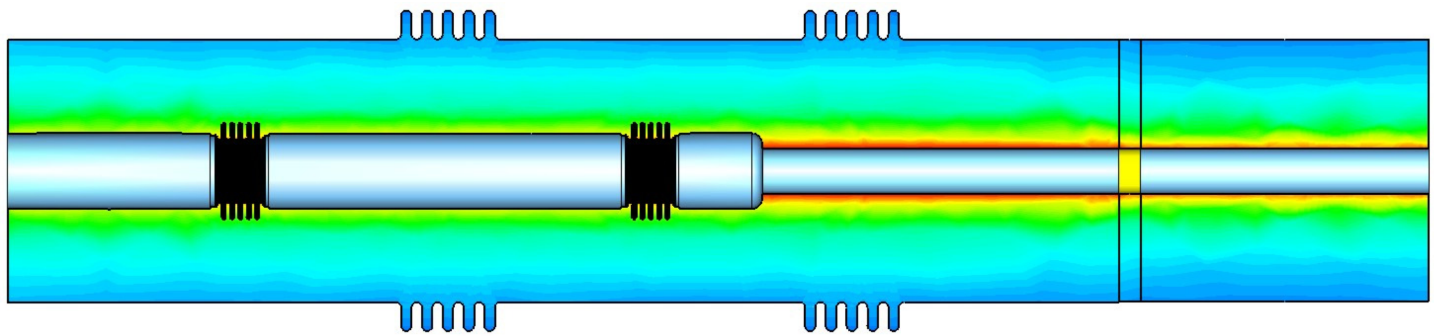


S11 is not too sensitive to ceramic dielectric constant



Max. E-field, air breakdown limit > 1 MW, TW

E-field



H-field

Loss (copper, bronze) ~ 0.082%   6 kW -> 5W, 30 kW –> 25W

Loss in ceramic = 0.4*δ   δ – loss tan.

δ= 0.001   6kW -> 2.4W,   30kW -> 12W

Vacuum part

Loss in antenna ~ 0.045% , 6kW -> 2.7W, 30 kW -> 13.5W

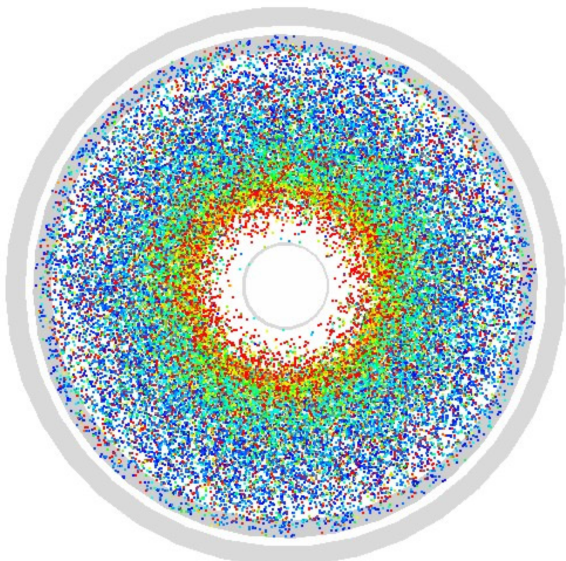
Loss in outer conductor (no copper coating):
6kW -> 1.2W, 30kW -> 6W

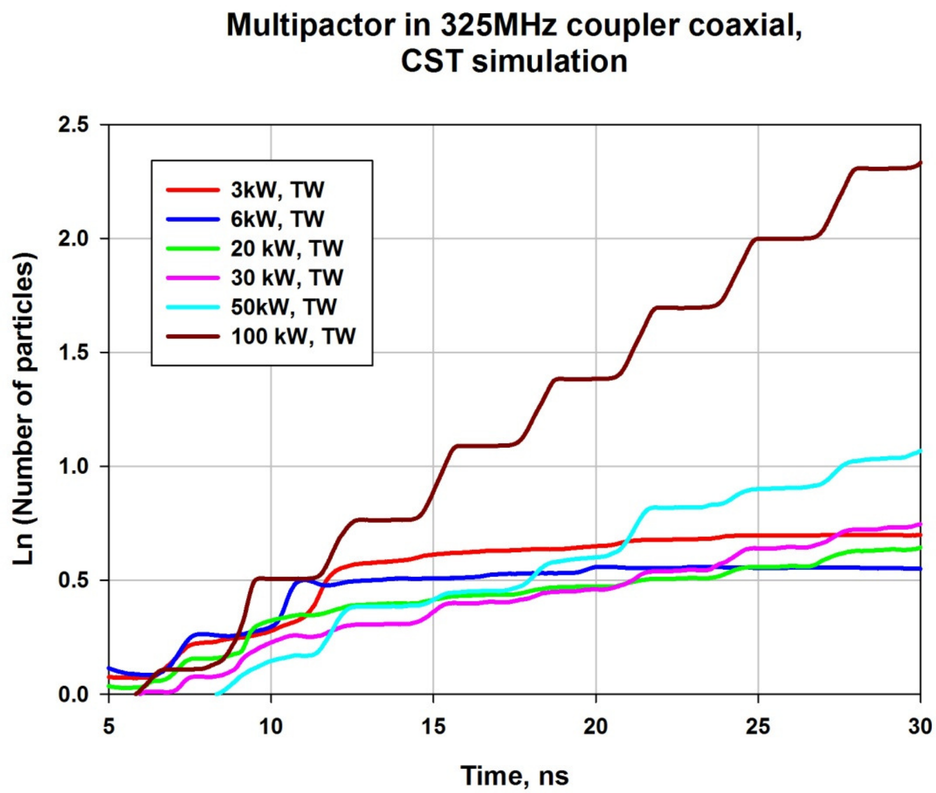
Loss in outer conductor (10um copper coating)
6kW -> ~ 0.1W, 30kW -> 0.5W

Total loss of coupler ~ 0.17%

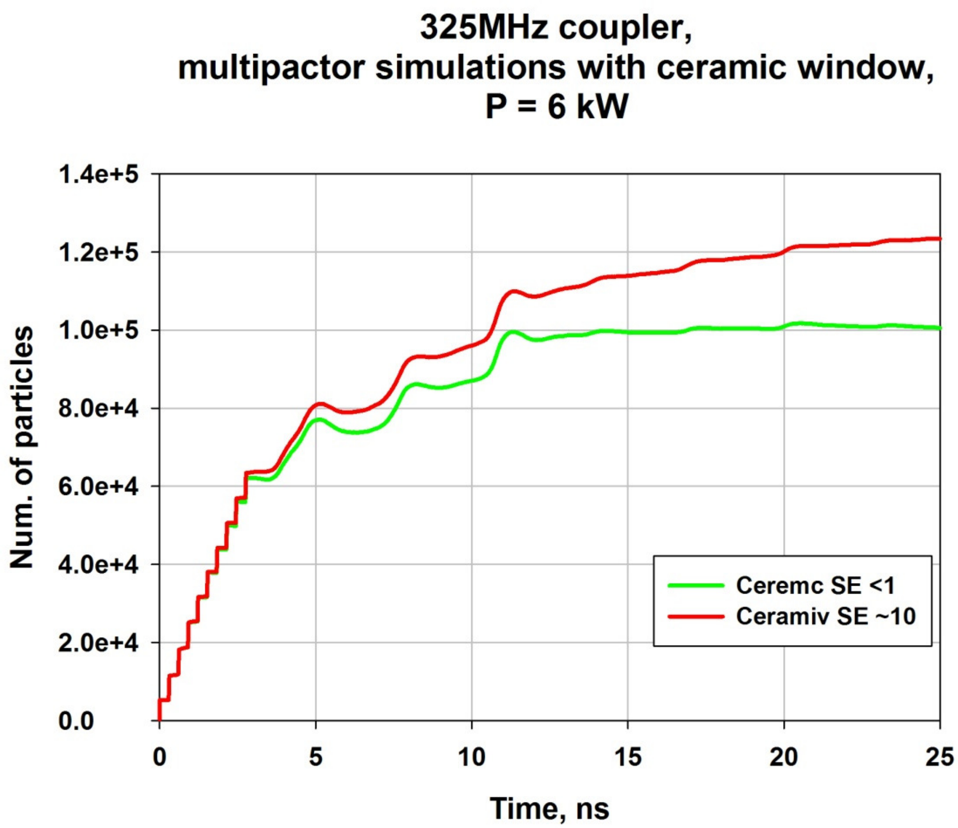
6kW -> 10W, 30kW ->50W

Multipactor simulation by CST studio





Noticeable multipactor starts at power (TW) > 30 -50 kW.



Ceramic presence shows small effect in CST studio: E-field is parallel of ceramic surface. But model is not accurate enough. It does not take into account an electric charge at the ceramic surface. Charge causes a perpendicular motion and can generate multipactor.

Ceramic will be coated by TiN

Hopefully, there will be no multipactor in PXIE and PX 1mA

Thermal properties

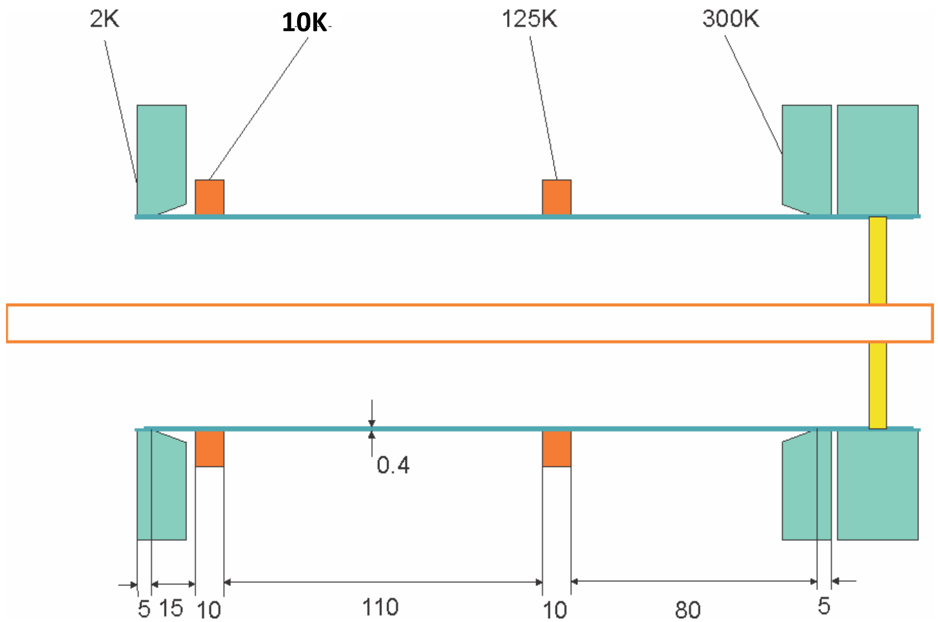
New in this design (comparatively with half year ago):

We understood, that that thermo-interception is technically not simple task.

To decrease static loss, a thickness of SS tube (outer conductor) was decreased to minimum 0.4mm

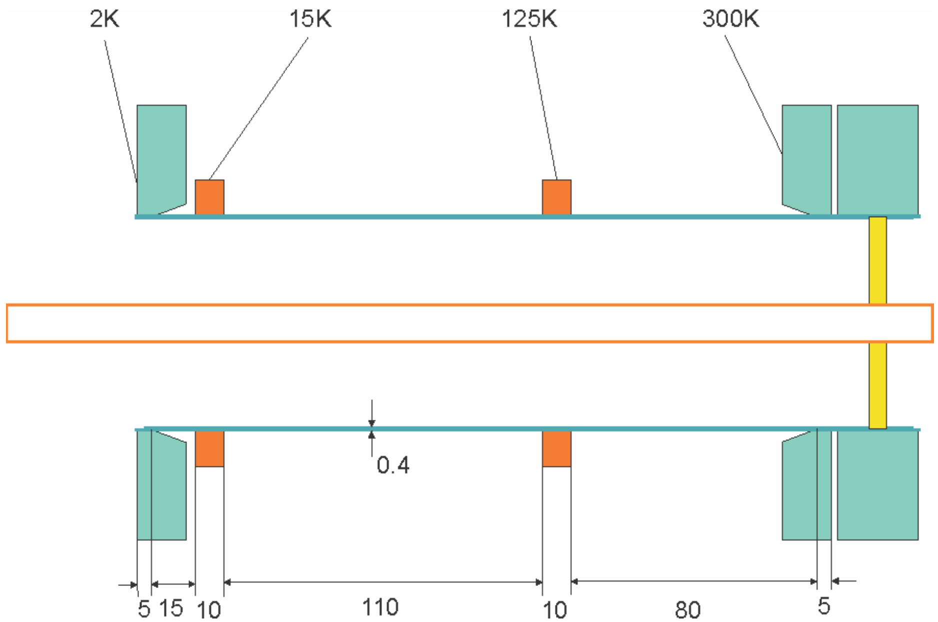
To get realistic cross-section arias of stripes, intercepting temperatures were increased: 5K -> 10K, 15K;   80K -> 125K

Outer conductor, 0.4mm SS, no cupper coating, interceptors 10K, 125K



	P_2K / P_pl, W	P_10K / P_pl, W	P_125K / P_pl, W	P_pl total, W	
Pin = 0kW	0.023 / 20	0.63 / 164	2.01 / 40	224	Static loss
Pin = 3kW	0.067/ 58	0.84 / 218	2.35 / 47	323	PXIE
Pin = 6kW	0.11 / 95	1.07 / 278	2.67 / 53	426	PX , 1mA
Pin = 20 kW	0.32 / 275	2.12/ 551	4.25 / 85	911	PX, 5mA, no overhead
Pin = 30 kW	0.46/ 396	2.87 / 746	5.36 / 107	1249	PX, 5mA, with overhead

Outer conductor, 0.4mm SS, no cupper coating, interceptors 15K, 125K



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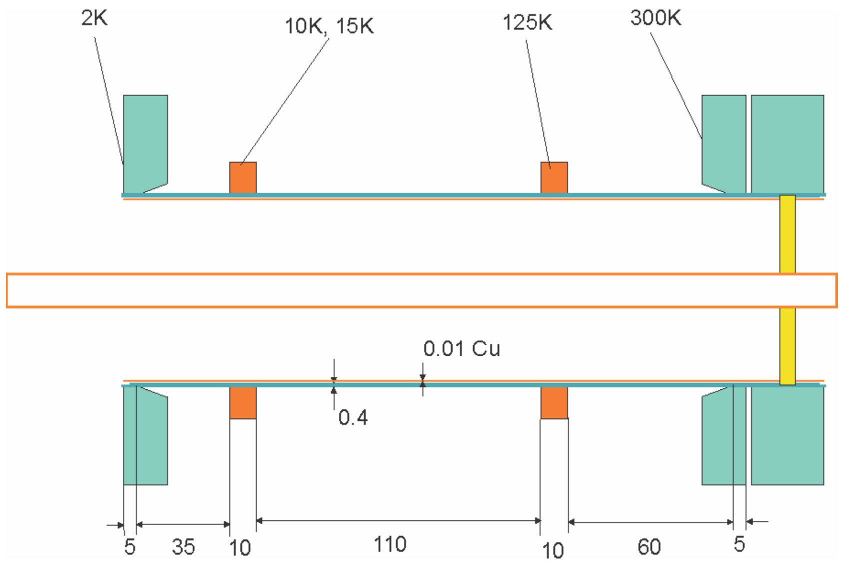
Pin = 0kW	0.06 / 52	0.58 / 151	2.02 / 40	243	Static loss
Pin = 3kW	0.10 / 86	0.81 / 211	2.35 / 47	344	PXIE
Pin = 6kW	0.15 / 129	1.03 / 268	2.68 / 54	451	PX , 1mA
Pin = 20 kW	0.35 / 301	2.07 / 538	4.25 / 85	924	PX, 5mA, no overhead
Pin = 30 kW	0.50 / 430	2.82 / 733	5.36 / 107	1270	PX, 5mA, with overhead

Outer conductor, 0.4mm SS, 10um cupper coating, interceptors 10K, 125K



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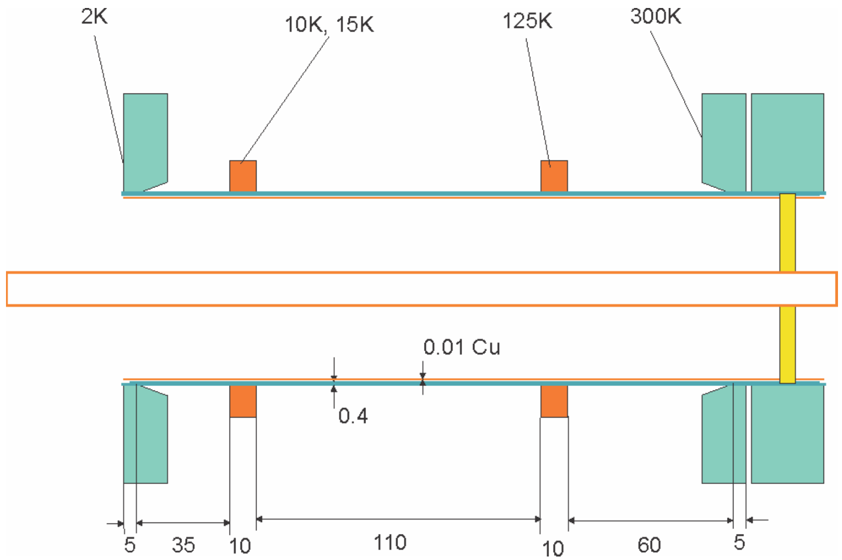
Pin = 0kW	0.1 / 86	1.95 / 507	4.28 / 86	679	Static loss
Pin = 3kW	0.1 / 86	1.97 / 512	4.32 / 86	684	PXIE
Pin = 6kW	0.1 / 86	1.99 / 517	4.34 / 87	690	PX , 1mA
Pin = 20 kW	0.12 /103	2.05 / 533	4.47 / 89	725	PX, 5mA, no overhead
Pin = 30 kW	0.13 / 112	2.10 / 546	4.58 / 92	750	PX, 5mA, with overhead

Outer conductor, 0.4mm SS, 10um cupper coating, interceptors 15K, 125K



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Pin = 0kW	0.24 / 206	1.76 / 458	4.33 / 87	751	Static loss
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Pin = 6kW	0.25 / 215	1.79 / 465	4.38 / 88	768	PX , 1mA
Pin = 20 kW	0.27 /232	1.86 / 484	4.52 / 90	806	PX, 5mA, no overhead
Pin = 30 kW	0.28 / 241	1.91 / 497	4.63 / 93	831	PX, 5mA, with overhead

10K intercept

To coat or not to coat?

	P_2K / P_pl, W	P_10K / P_pl, W	P_125K / P_pl, W	P_pl total, W	
Pin = 0kW	0.023 / 20	0.63 / 164	2.01 / 40	224	Static loss
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15K intercept

	P_2K / P_pl, W	P_15K / P_pl, W	P_125K / P_pl, W	P_pl total, W	
Pin = 0kW	0.06 / 52	0.58 / 151	2.02 / 40	243	Static loss
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Pin = 30 kW	0.28 / 241	1.91 / 497	4.63 / 93	831	PX, 5mA, with overhead

PXIE and PX 1mA do not require a copper coating of 325MHz coupler.

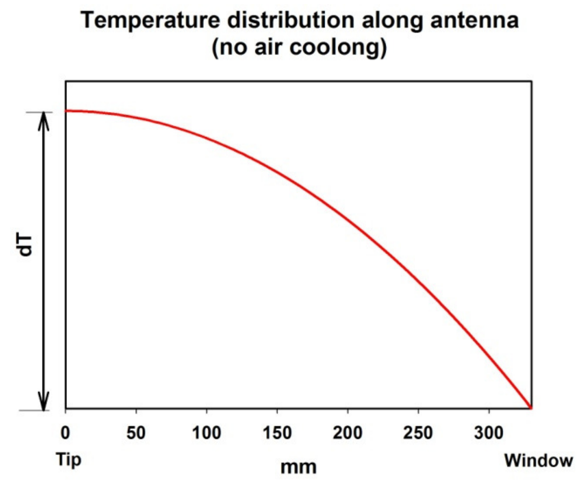
PX 5 mA - It is better to coat

Shell we try both at test stand and PXIE?

Antenna cooling

Antenna – 0.5'' tube (12.7mm) , wall thickness - 1.57mm, length ~ 330mm (from window to tip)

Temperature distribution (no air cooling):



$T_{tip} = T_0 + dT$ $\quad\quad$ $T_0 \sim 310$ K (~ 36.6 C)

P_{in} = 6 kW, dT = 16.7 K, T_{tip} ~ 327 K (~54 C)
P_{in} = 30 KW, dT = 83.4 K, T_{tip} ~ 393 K (~120 C)

Thermal radiation:
Antenna radiation length (looks at SC) ~ 70mm
Radiating aria ~ 2800 mm^2
Emissivity factor ~ 0.05

P_{rad} (6kW) ~ 0.1W

P_{rad} (30kW) ~ 0.2W

It seems coupler can work without air cooling if emissivity factor ~0.05
Emissivity factor ~0.1 requires air cooling for P_{in} = 30kW

Cooling of the antenna by the radiation without RF power

In previous slide:
Ohmic loss at antenna surface for 6kW RF power is about ~2.2W and gives temperature rise ~ 17C.

It means that radiation ~2.2W will decries a temperature tip ~ 17C.
But radiation is not more then 0.1W x 5 = 0.5W (70mm x 5 = 350mm)
for emissivity 0.05 and not more 1W for emissivity 0.1.

Temperature of antenna tip will be > 0 C even without RF power.

Thermo-interceptors

It supposes to be two base temperature in cryomodule for interception: “5K” and “80K”. Parameters and ability of “pipes” is not clear yet.

Temperature of coupler intercept points has to be higher then temperature of “pipes” to provide temperature gradient and acceptable cross-section areas of stripes.

Estimation of stripes crass-section areas:

“5 K”

Copper thermo conductivity ~ 700 W/(K*m)
Power ~ 3W
Length ~ 0.3m

Gradient dT ~ 5K -> S ~ 260 mm^2
Gradient dT ~ 10k -> S ~ 130mm^2

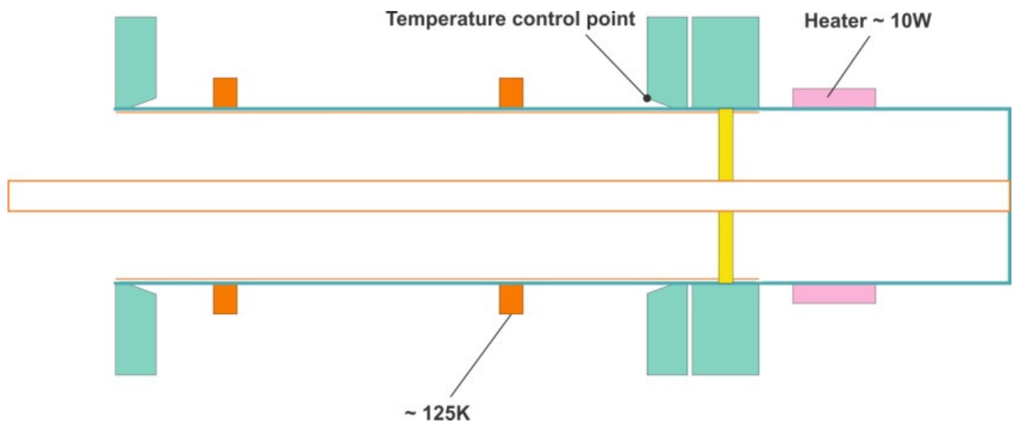
"80 K" Copper thermo conductivity ~ 400 W/K*m
Power ~ 6W
Length ~ 0.3m

Gradient dT ~ 30K (Pipe in PXIE ~ 95K ?) -> S ~150 mm^2

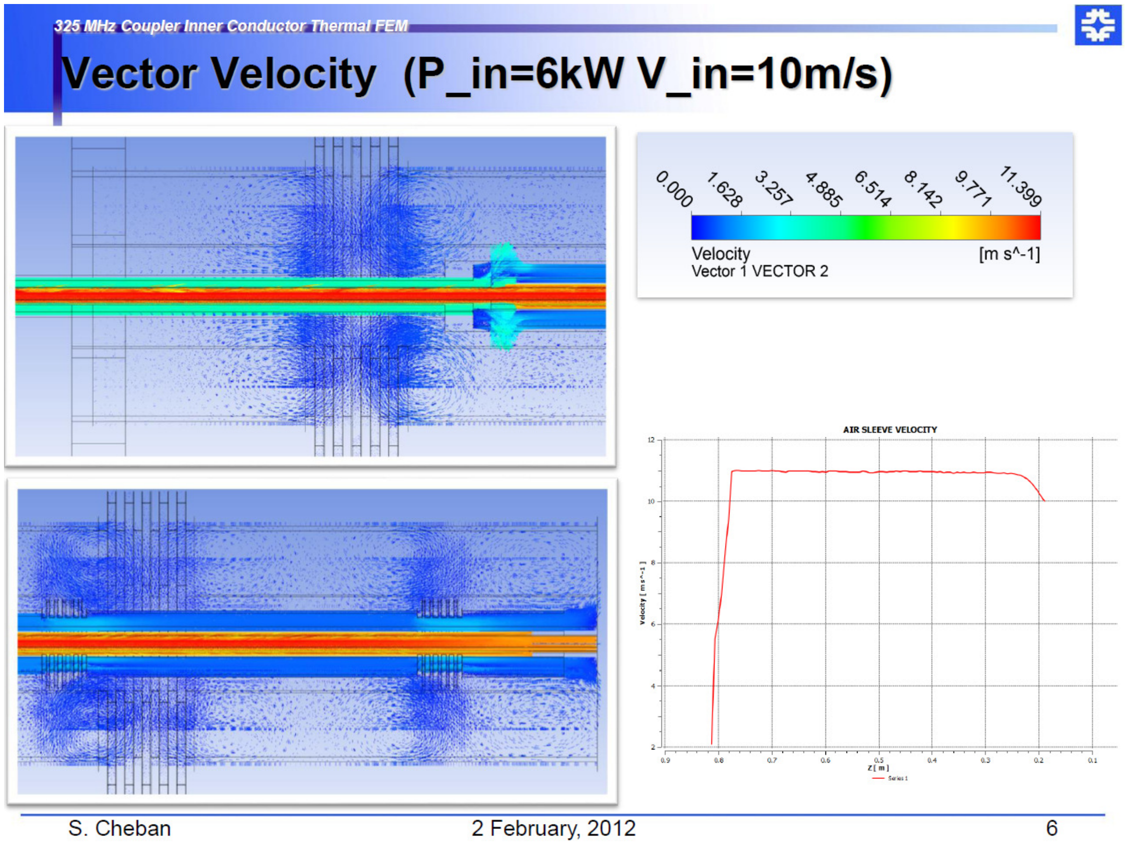
"300 K" Copper thermo conductivity ~ 400 W/K*m
Power ~ 4W
Length ~ 0.3m

Gradient dT ~ 5K -> S ~600 mm^2
Gradient dT ~10K -> S ~ 300mm^2 - quite thick stripes

It is better to keep window warmer then environment to avoid moisture on the surface.
The simplest solution is electric heater ~ 10W and temperature control.



Air cooling: Sergey Cheban will make detailed talk.



Short conclusions:

PXIE and 1mA PX do not require a air cooling for 325 MHz coupler.

Coupler of 5 mA PX has to be air cooled.

Possible diagnostics and interlocks:

•Direct, reflected power

•Temperature monitoring (2K?, 5K? 70K? 300K)

•E-pickup (activity in vacuum part)

•Arc detector

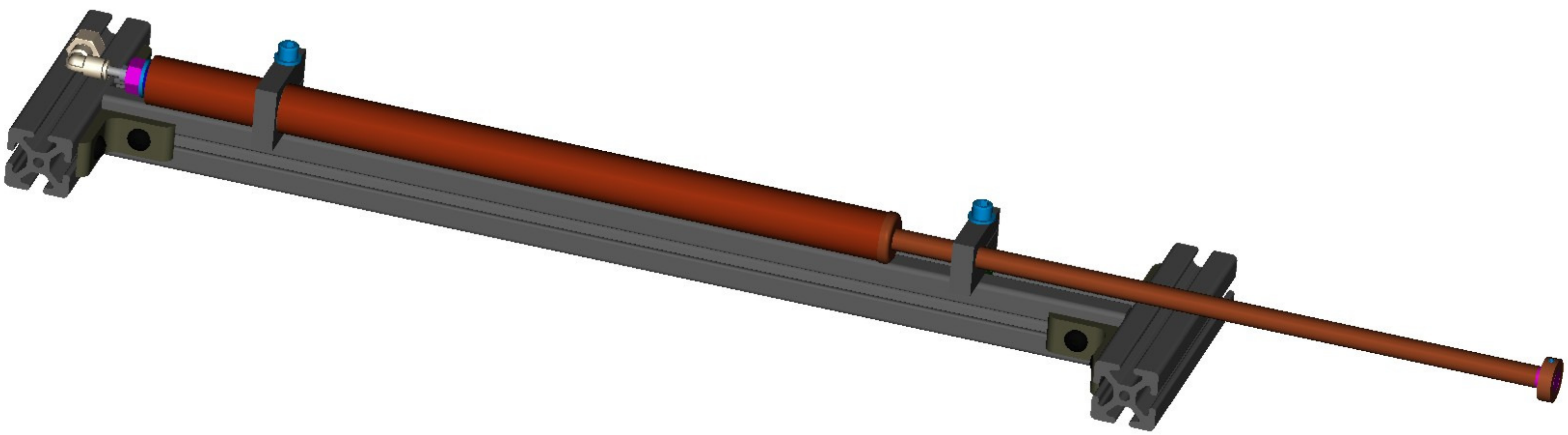
•No vacuum diagnostic – common vacuum with cavity

Preliminary tests we suppose to do:

Antenna assembling

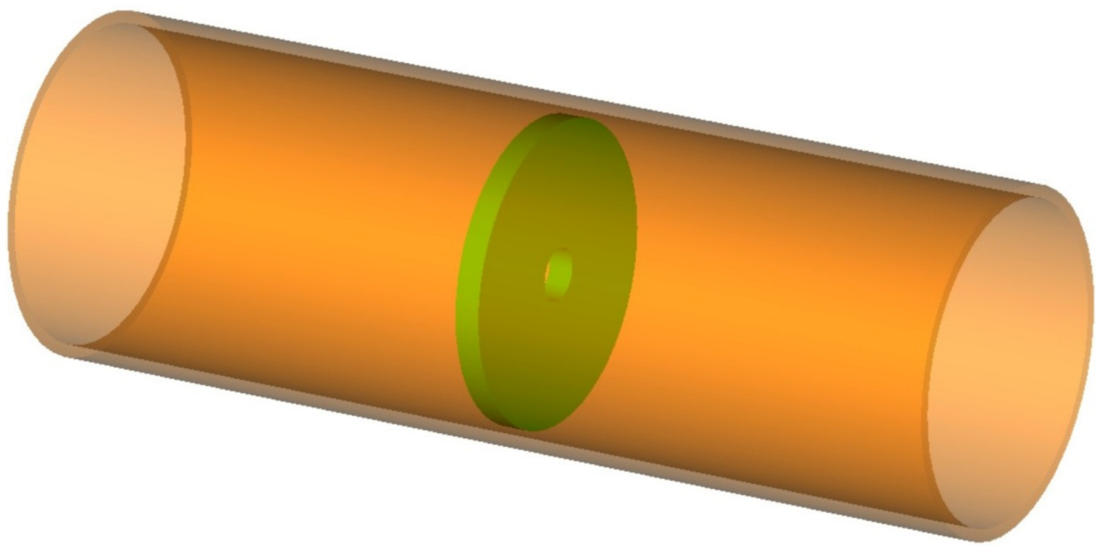
Issues to check:

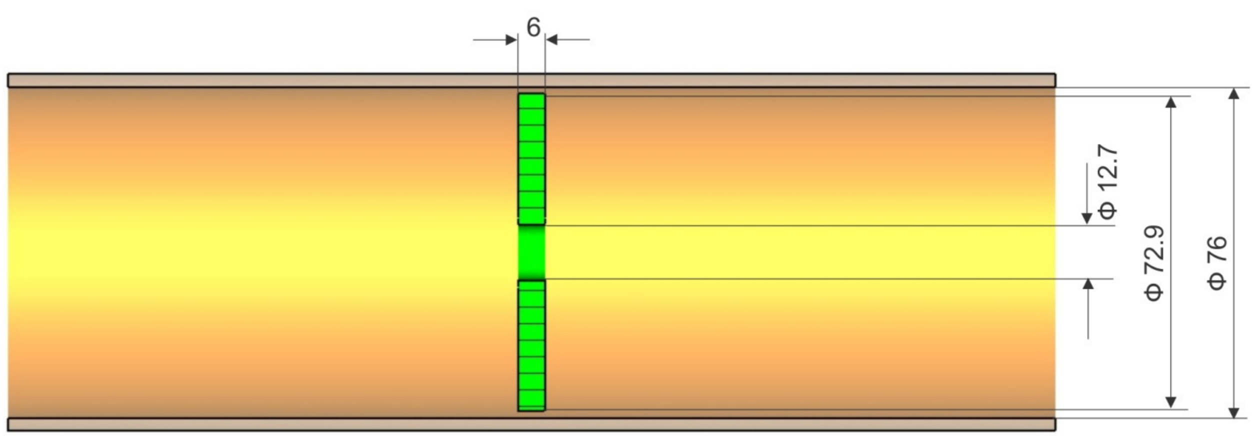
- Assembling
- Air cooling efficiency (power, temperature, air flow /pressure)
- Air flow noise
- Resonance frequency of antennas (325 MHz and 650 MHz)



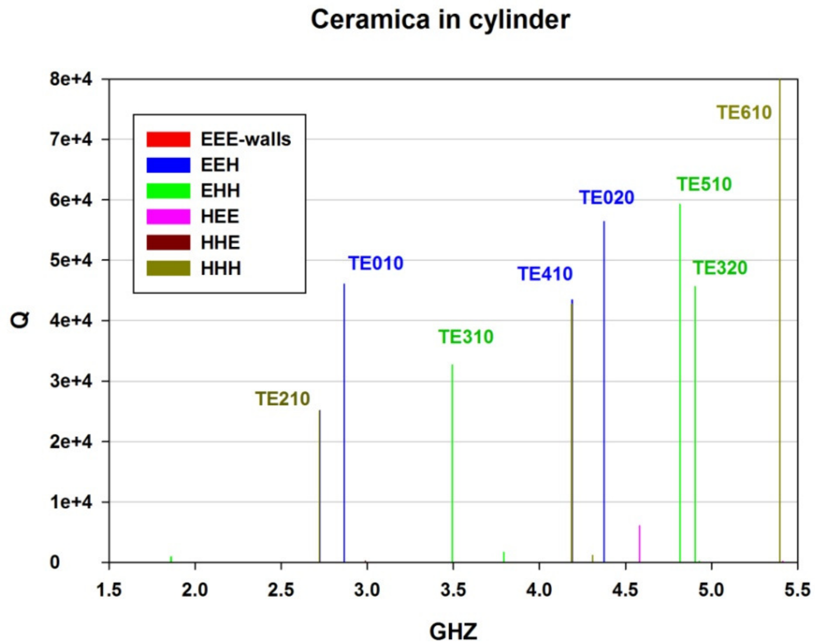
Assembling is ordered. Will be ready for measurement at the beginning of March

Measuring of ceramic properties

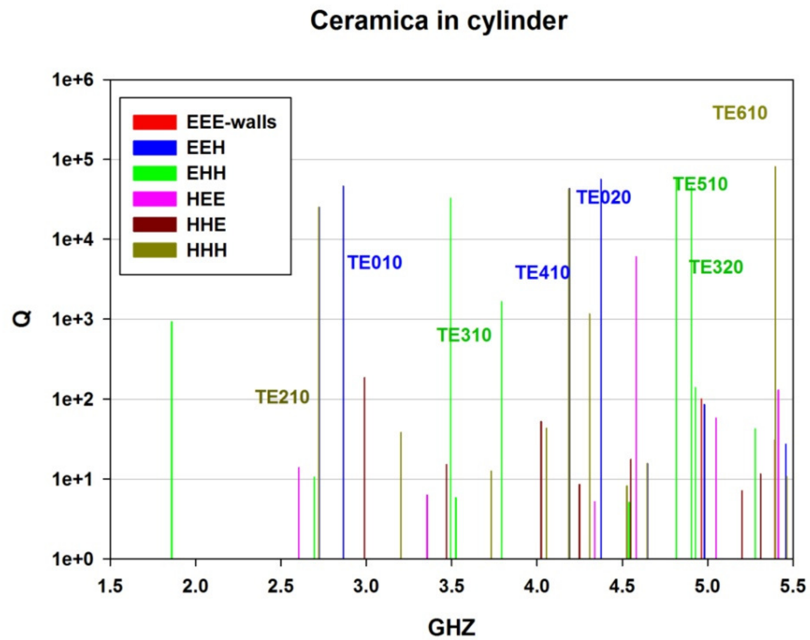




Resonances of assembly, no losses in ceramic, outer cylinder = copper, non-metallized ceramic



Linear scale



Logarithmic scale

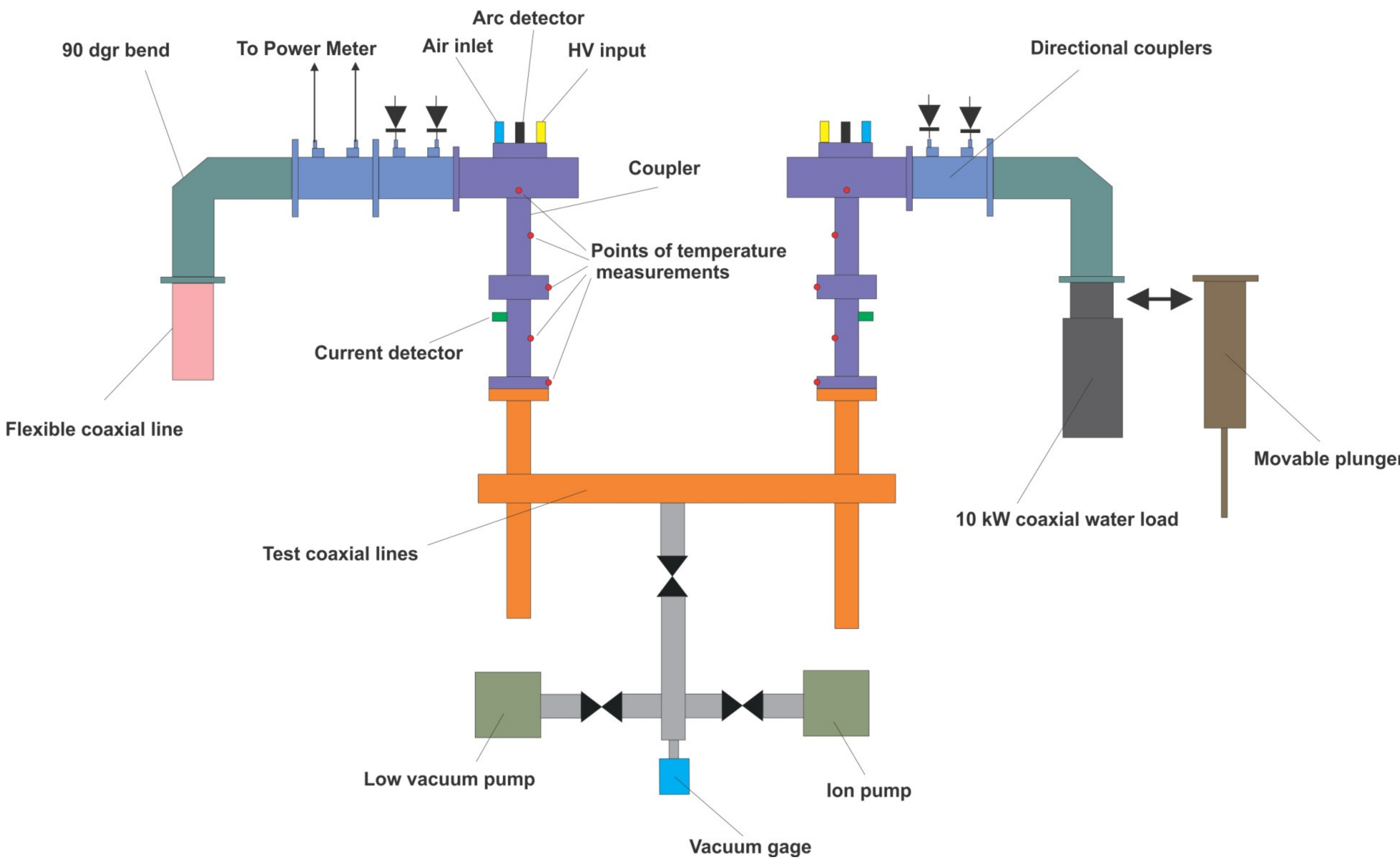
We can measure ceramic's properties at 3GHz -5GHz and extrapolate them to operating frequencies 325MHz and 650MHz.
It is rather difficult to make high-Q cavity (Q >1E+4) at operating frequencies.

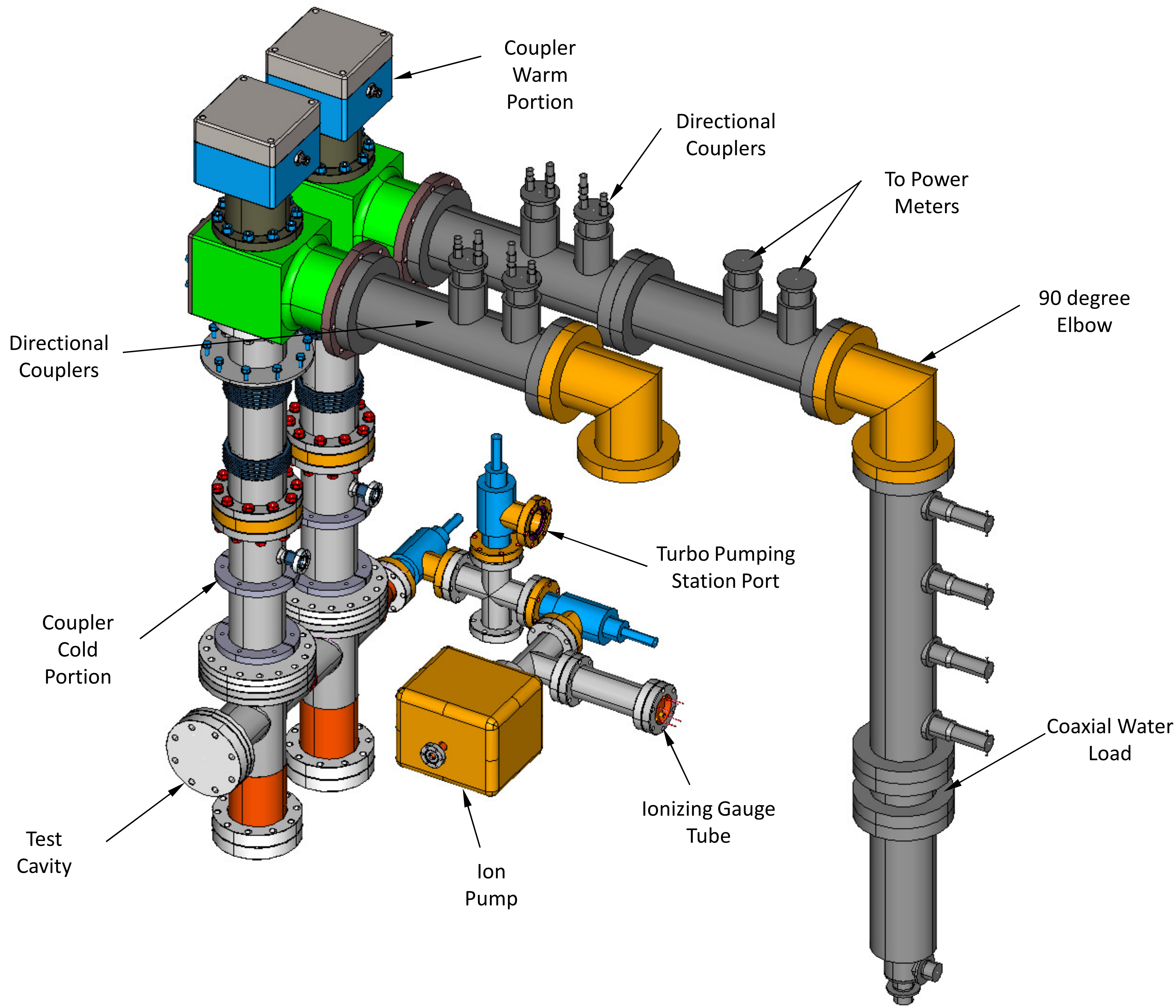
Coupler testing ant test stand

Test procedure:

- **Cleaning.**
- **Assembling pair of couplers (vacuum parts) with test cavity in clean room, vacuum leak check, pumping.**
- **Transportation to test place.**
- **Assembling at the test stand.**
- **Pumping and vacuum leak check.**
- **Baking.**
- **Air part assembling and low power RF check.**
- **Connecting RF parts. Low power measurements with RF parts.**
- **RF conditioning.**
- **Disassembling and transportation to clean room.**
- **Disconnecting test cavity and connecting storing volumes.**
- **Storing .**

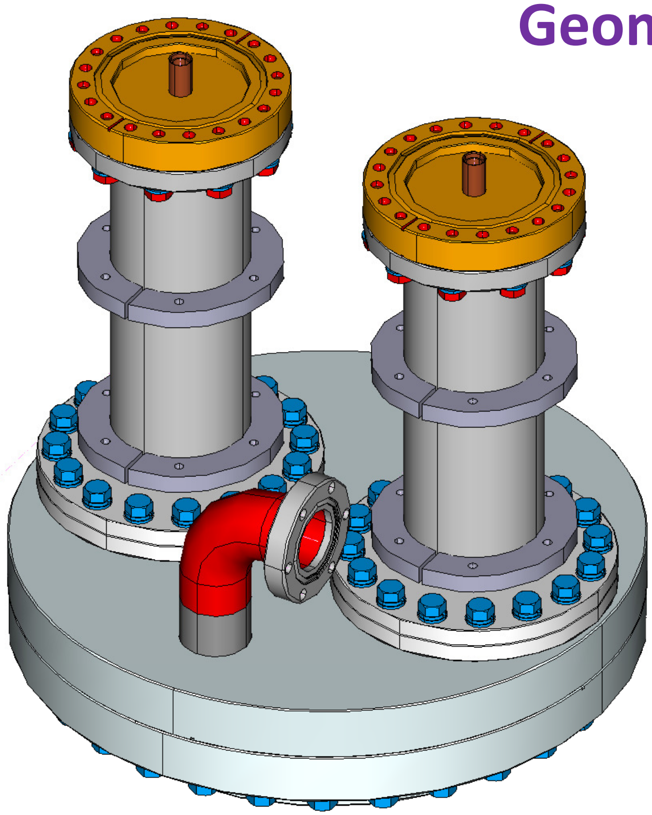
Block diagram of 325MHz coupler test stand



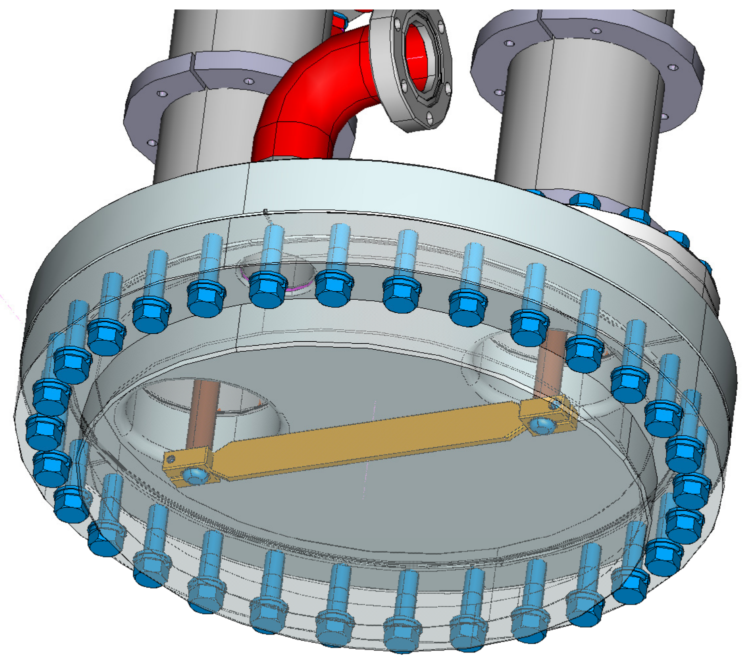

Coupler Warm Portion
Directional Couplers
To Power Meters
90 degree Elbow
Directional Couplers
Turbo Pumping Station Port
Coupler Cold Portion
Coaxial Water Load
Ionizing Gauge Tube
Test Cavity
Ion Pump

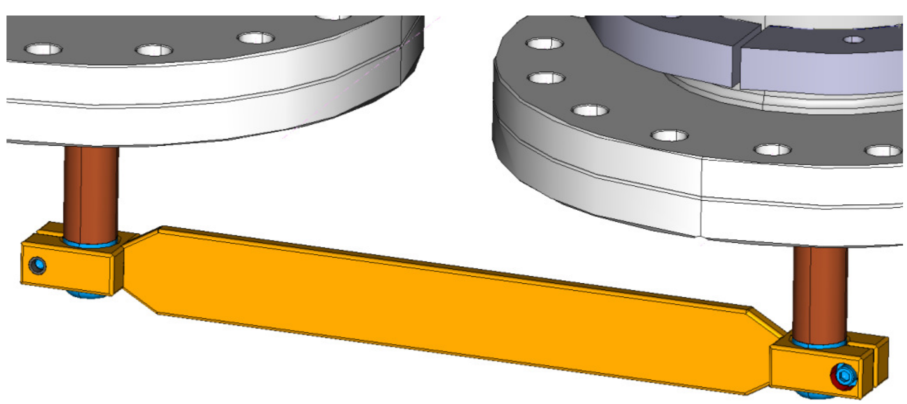
Possible geometries of test cavities

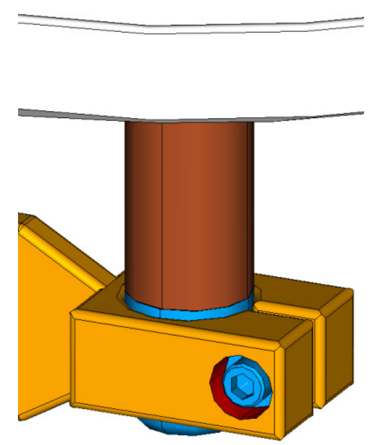
Geometry with mechanical contact

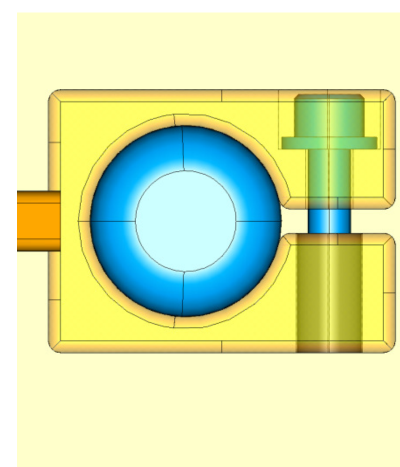


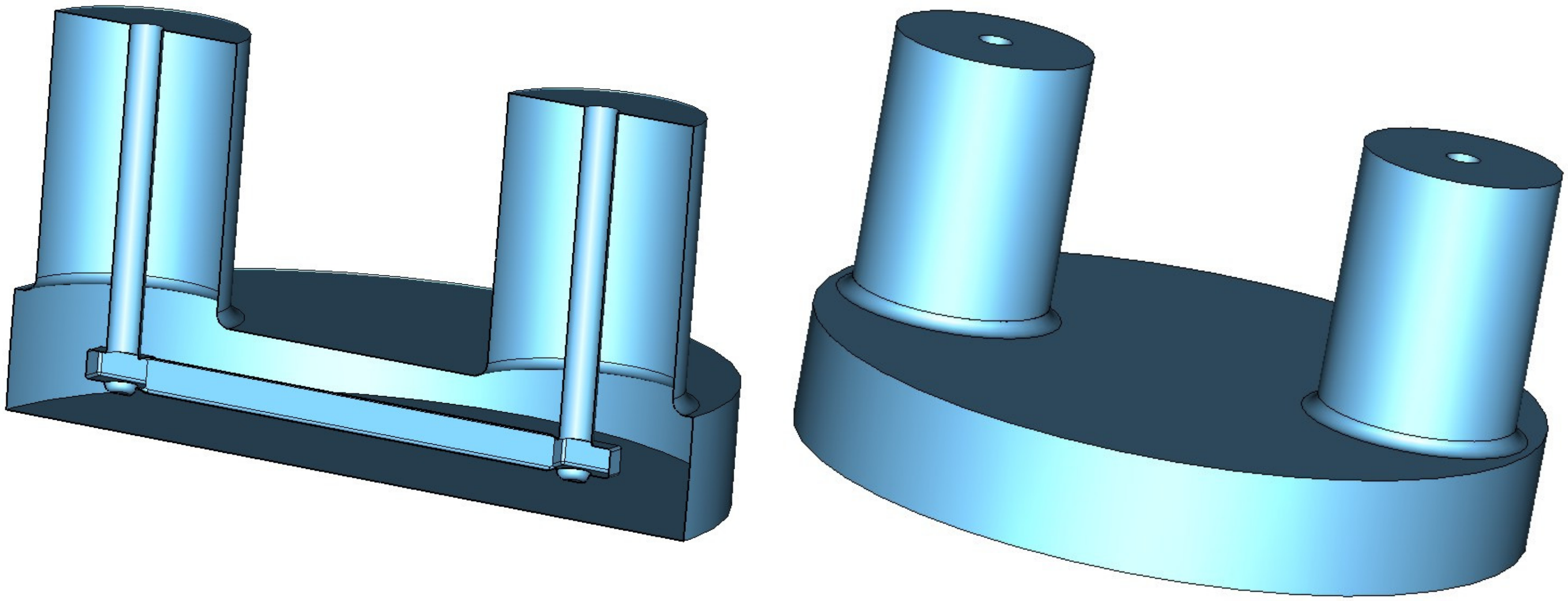
~90Lb
(41kg)







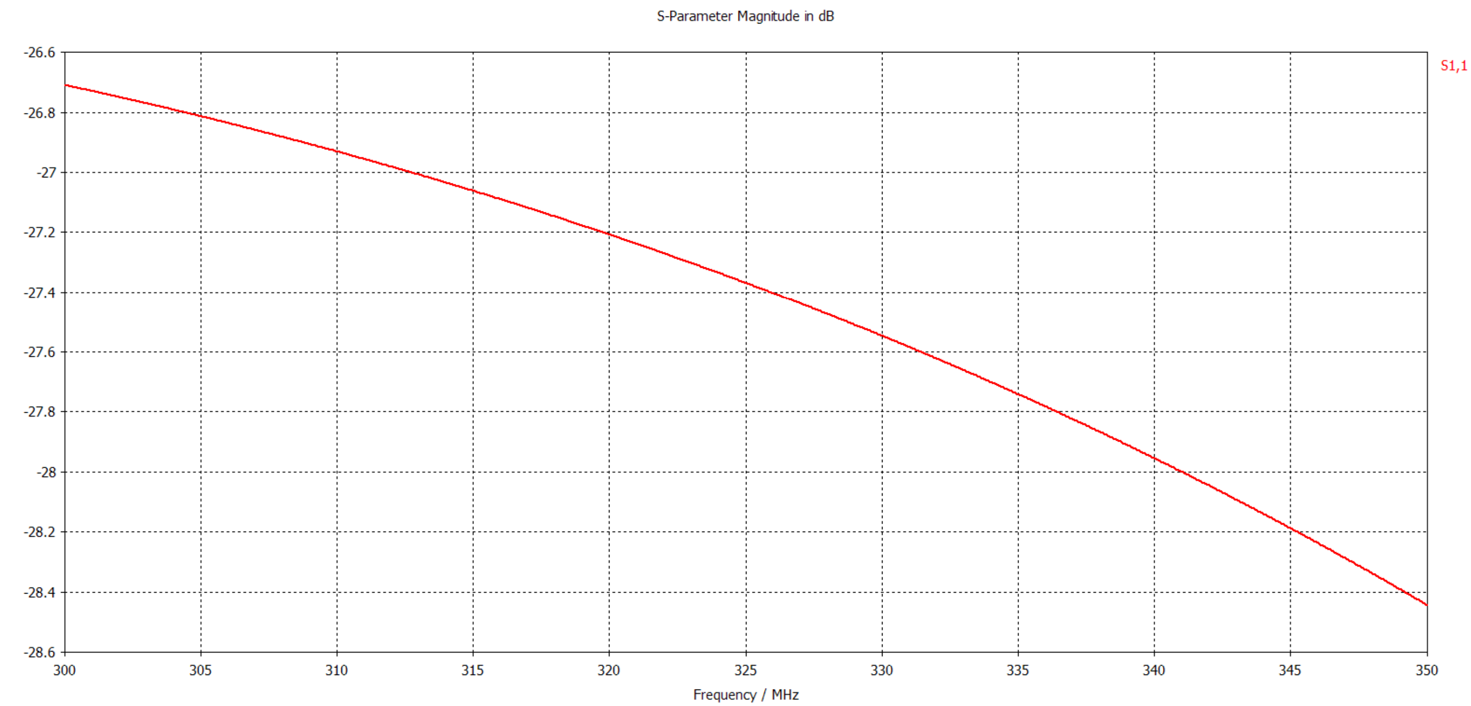


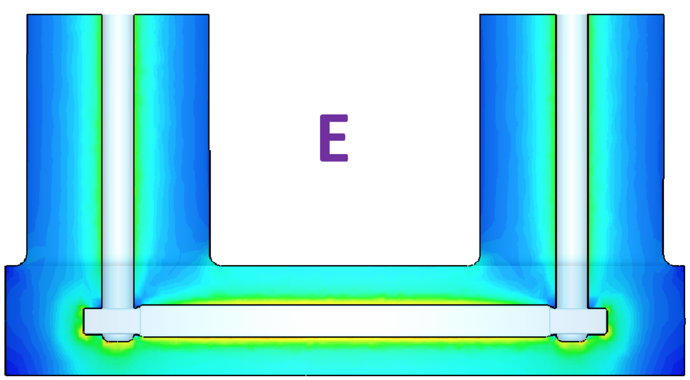


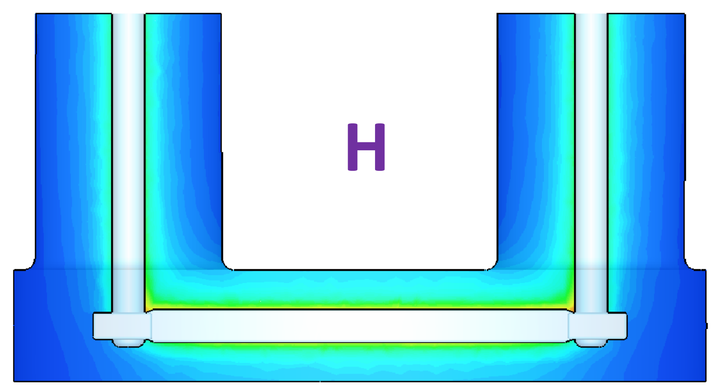
Pro: Small, simple and cheap

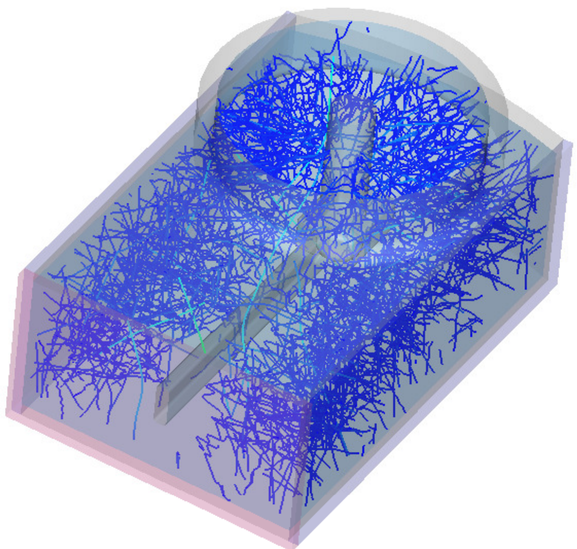
Cons: Mechanical contact at tip, multipactor suppression by HV bias (?)

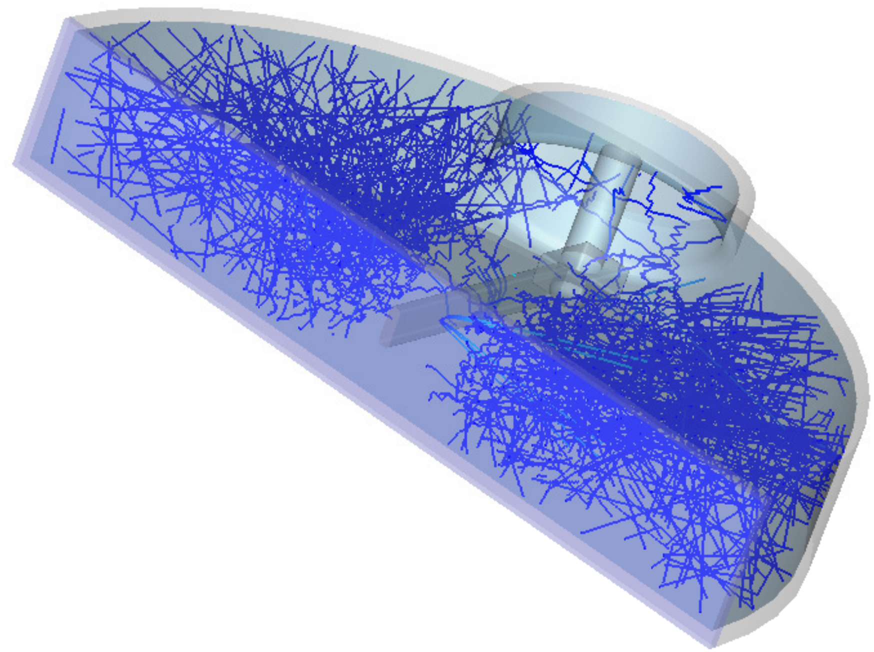
Note: Mechanical contact does not change any RF properties of antenna – RF power too small for RF breakdown and multipactor.
Only issue is generation of micro-particles.
Can we re-clean a tip after test?


S-Parameter Magnitude in dB
-26.6
-26.8
-27
-27.2
-27.4
-27.6
-27.8
-28
-28.2
-28.4
-28.6
300
305
310
315
320
325
330
335
340
345
350
Frequency / MHz
S1,1


E

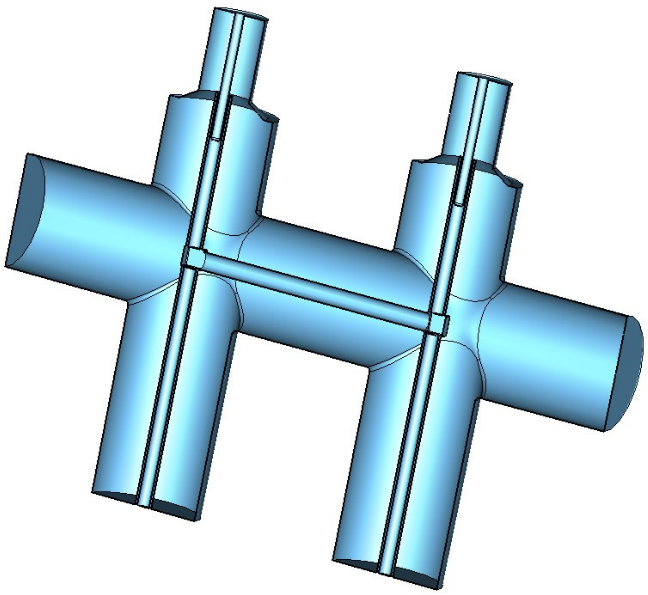

H

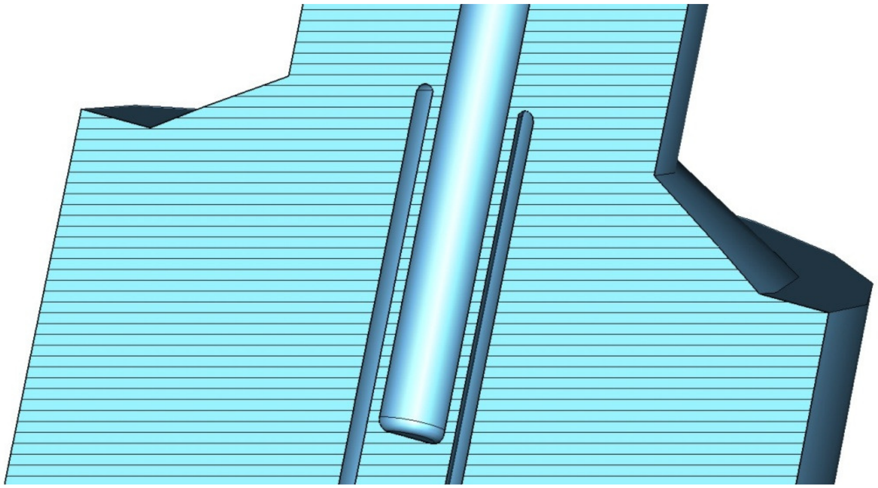




Multipactor thrashholde ~ 6 kW

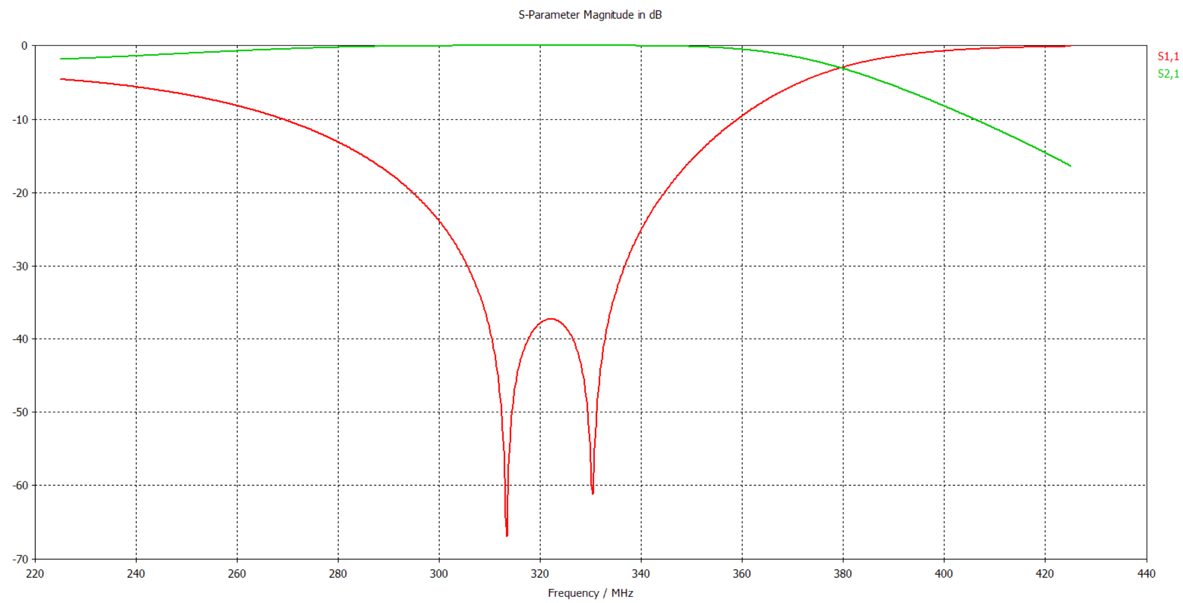
Geometry without mechanical contact

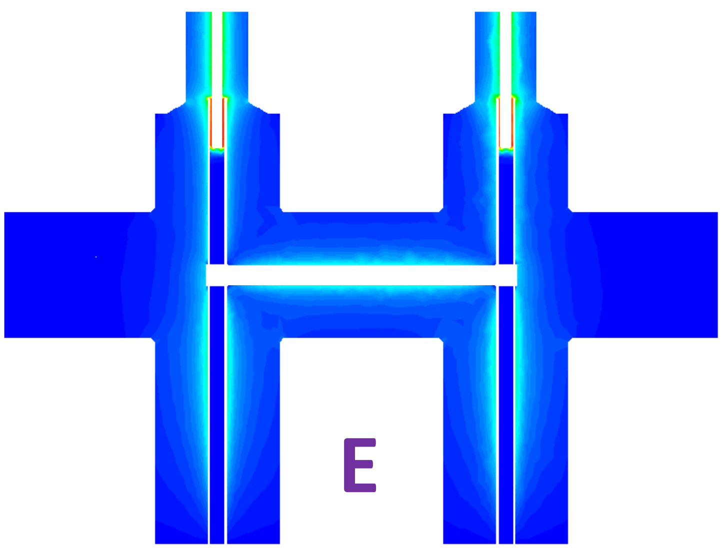


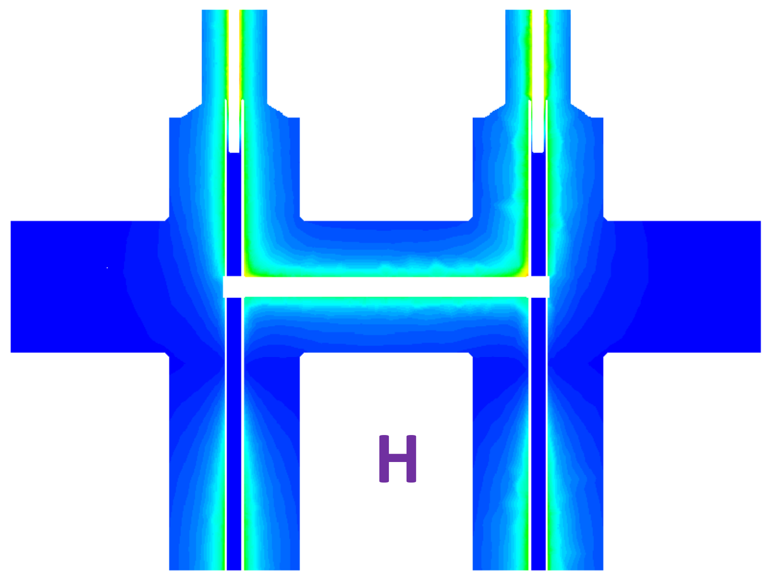


Pro: **no mechanical contact with antenna during test.**
No multipactor due to big size of coaxial.

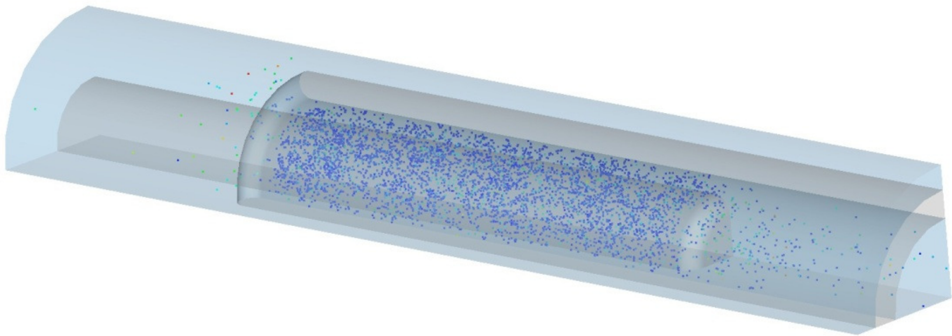
Cons: **Big sizes, heavier, more expensive,.**

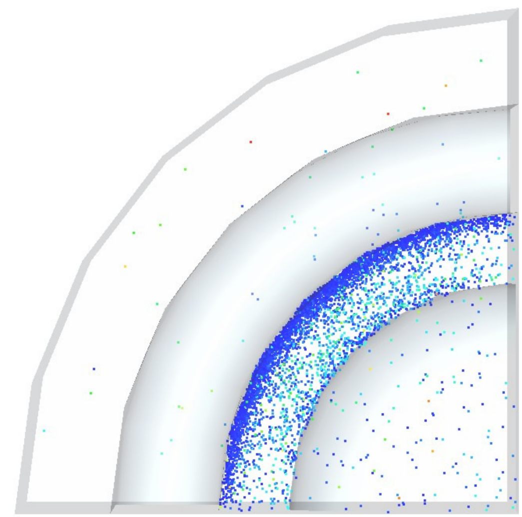

S-Parameter Magnitude in dB
0
-10
-20
-30
-40
-50
-60
-70
220
240
260
280
300
320
340
360
380
400
420
440
Frequency / MHz
S1,1
S2,1


E

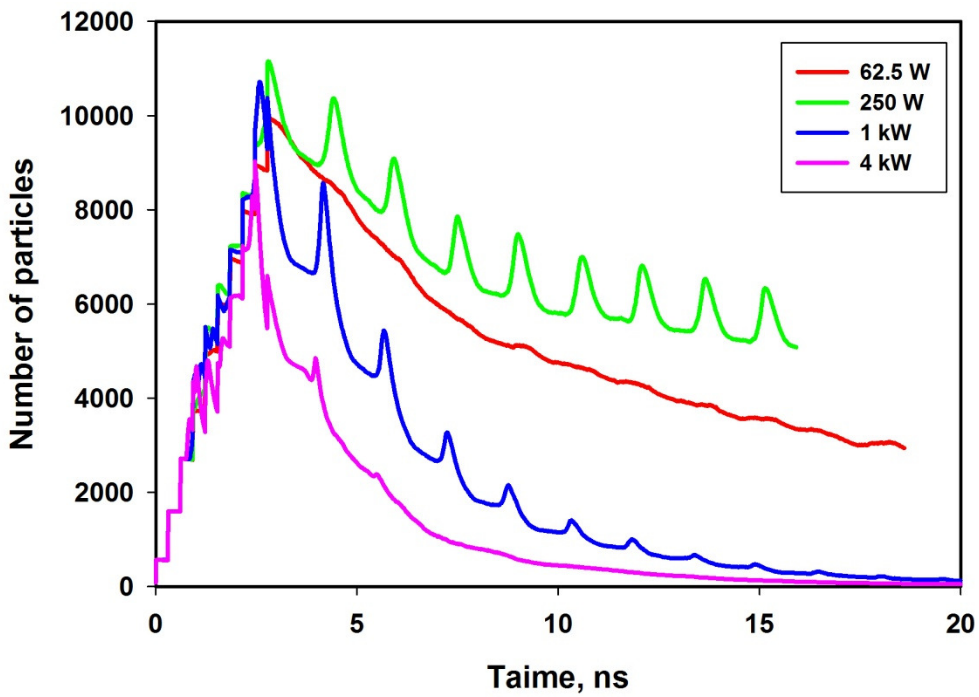

H

Multipactor in slot

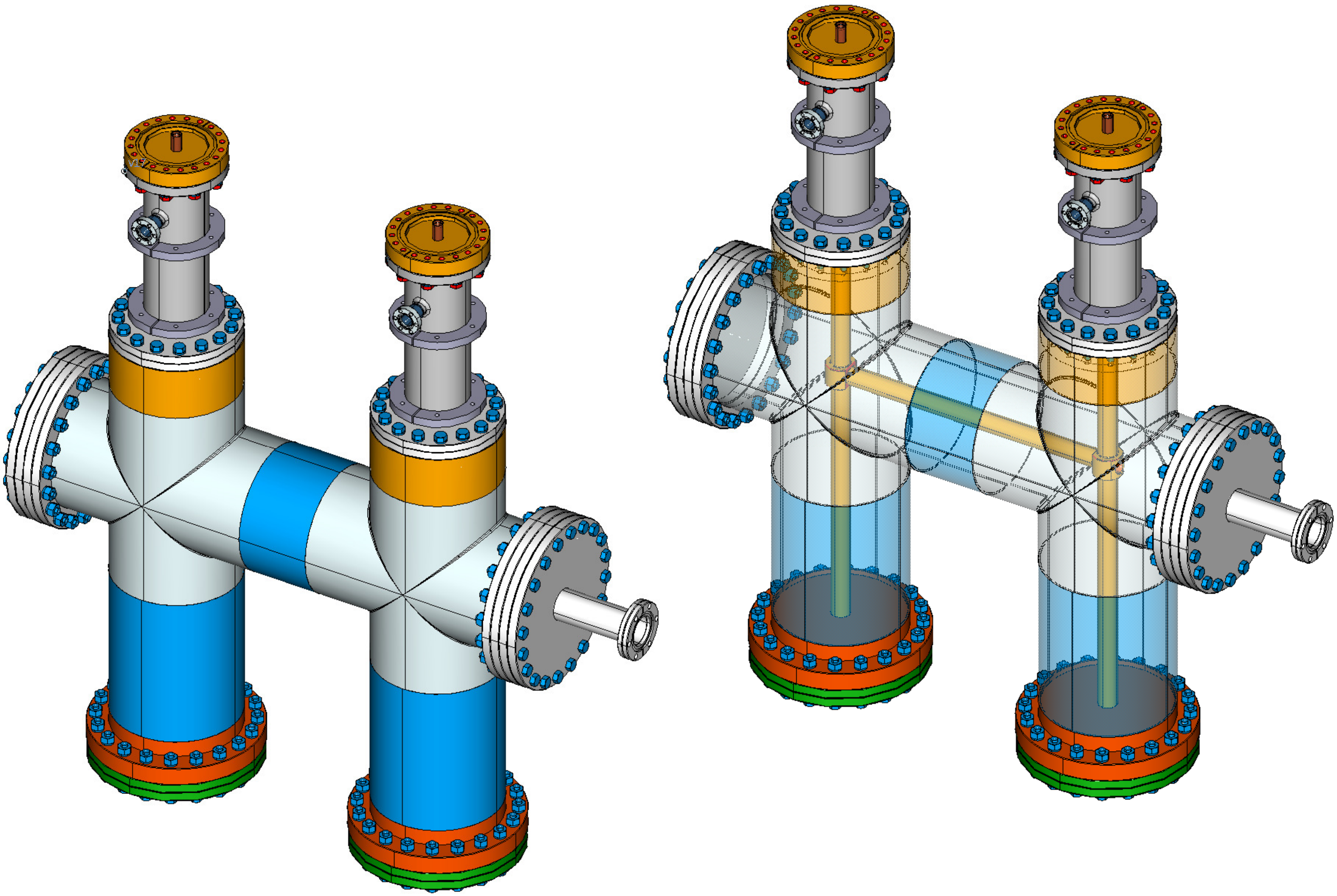


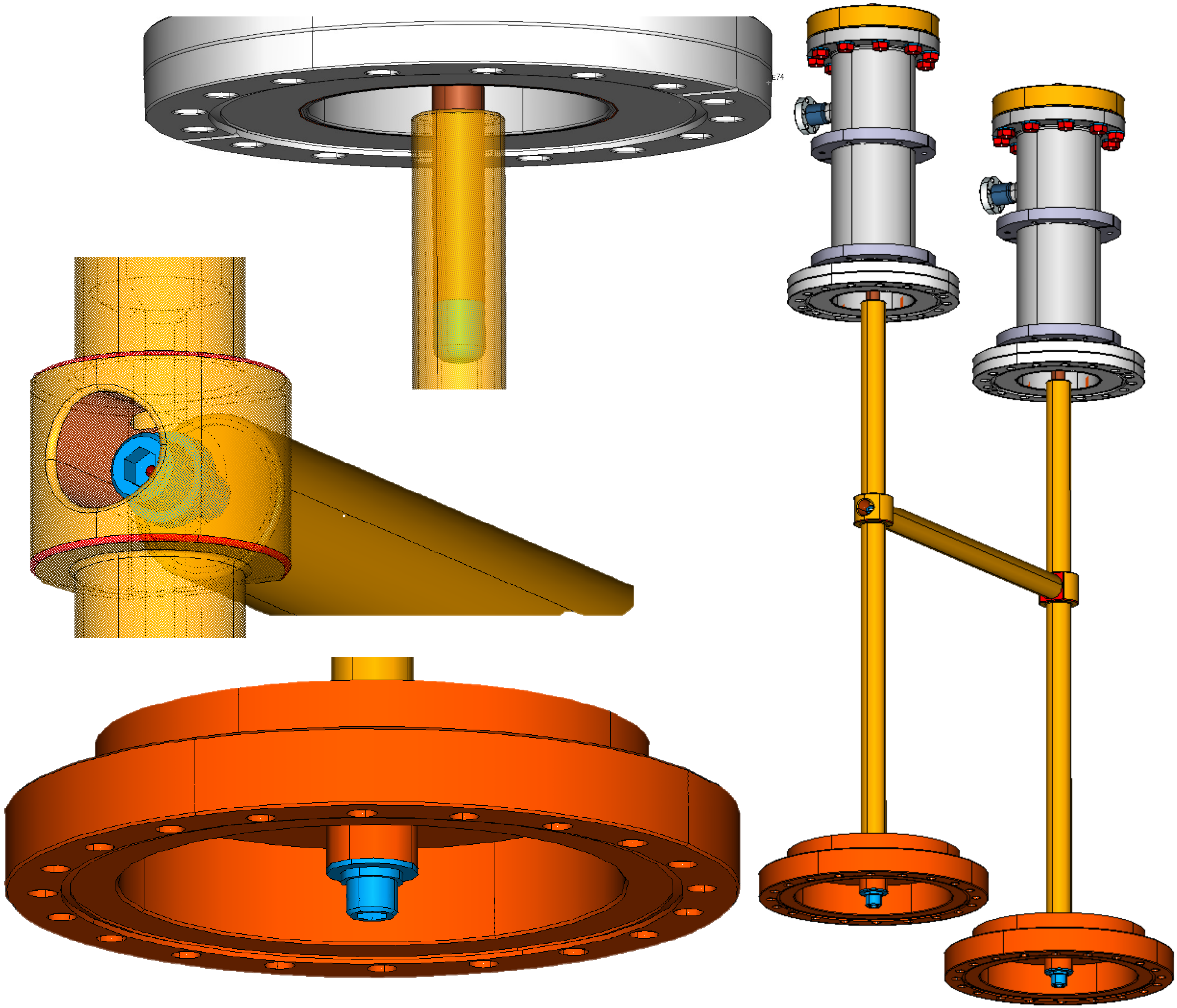


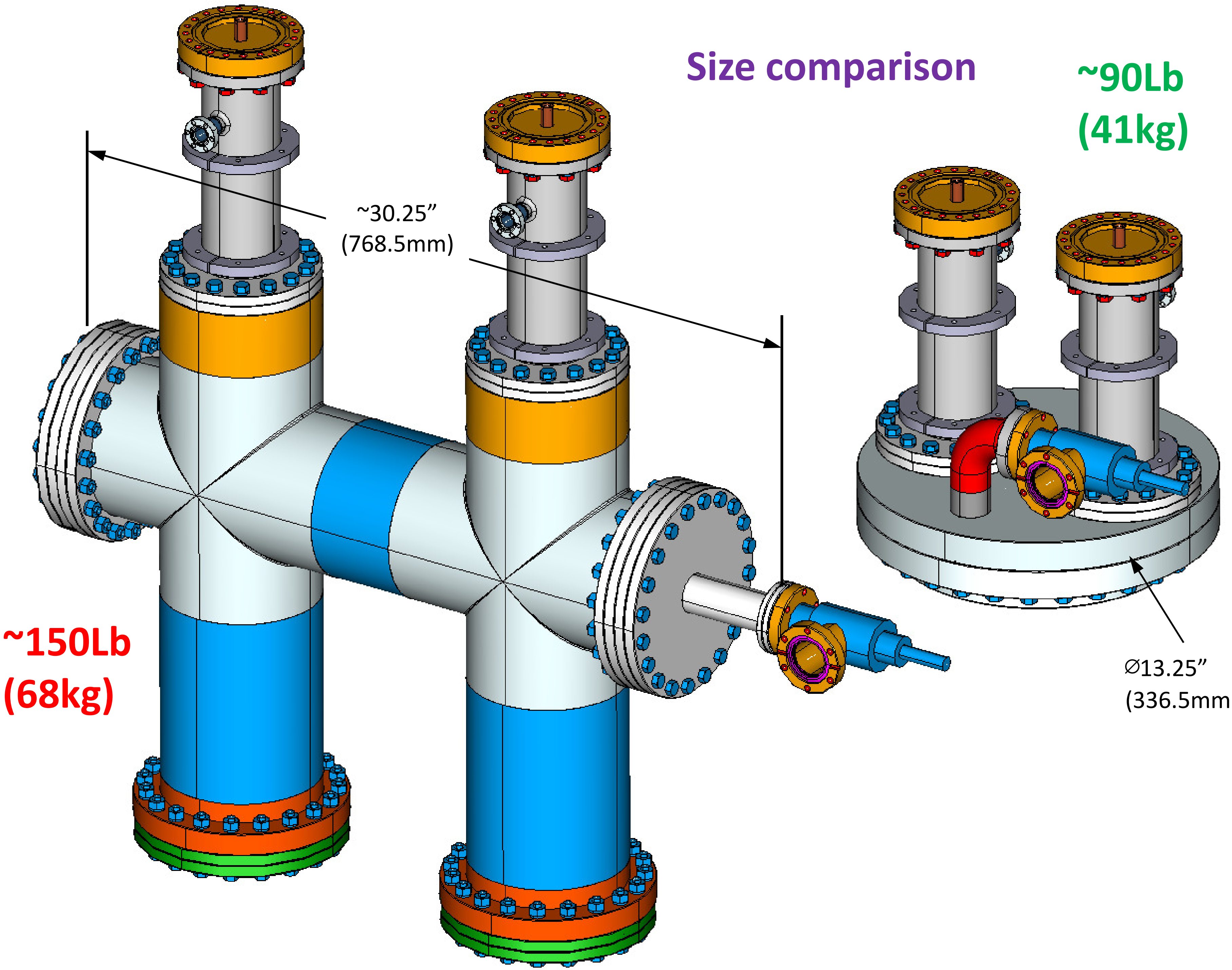
Multipactor in 2mm slot of
325 MHz coupler test cavity



It seems, the is **NO** multipactor in slot at interesting power range .







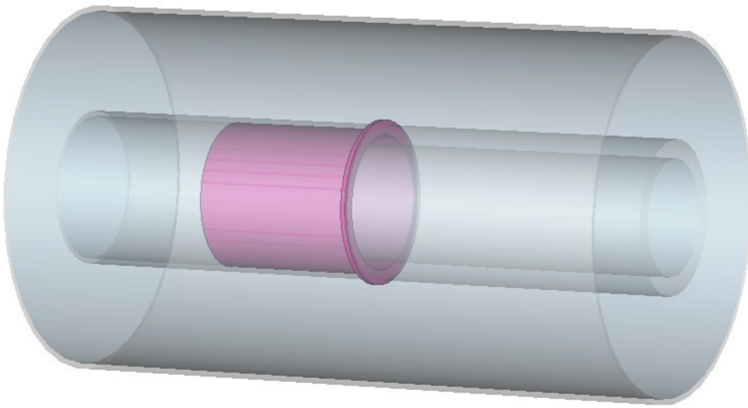
Size comparison
~90Lb
(41kg)
~30.25"
(768.5mm)
~150Lb
(68kg)
∅13.25"
(336.5mm)

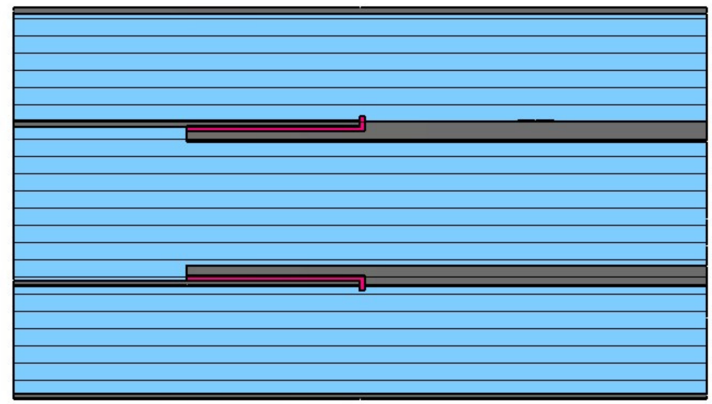
Conclusion:

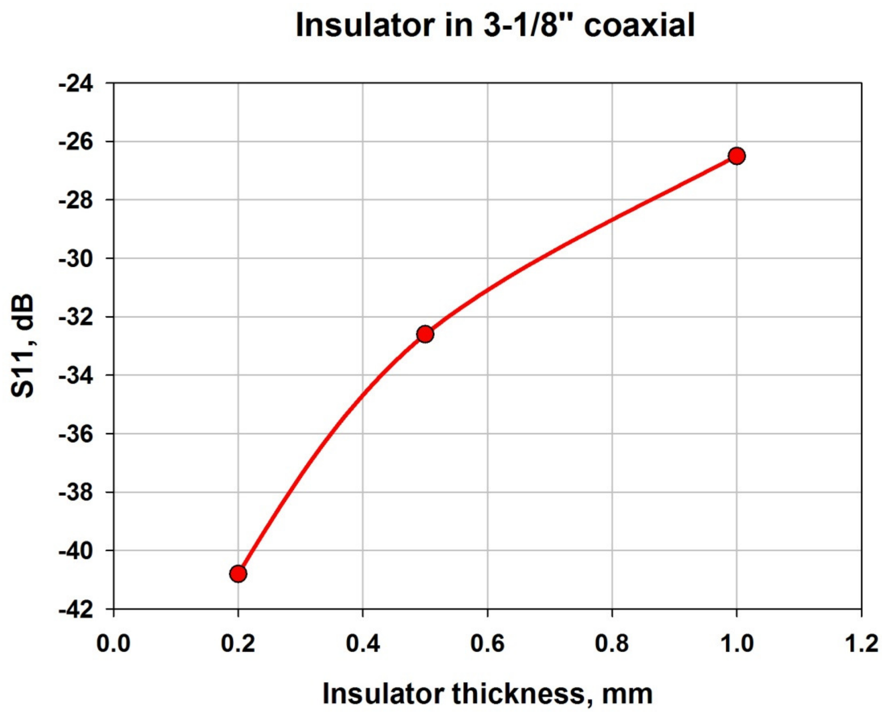
Reviewers will make a conclusion.

Backup

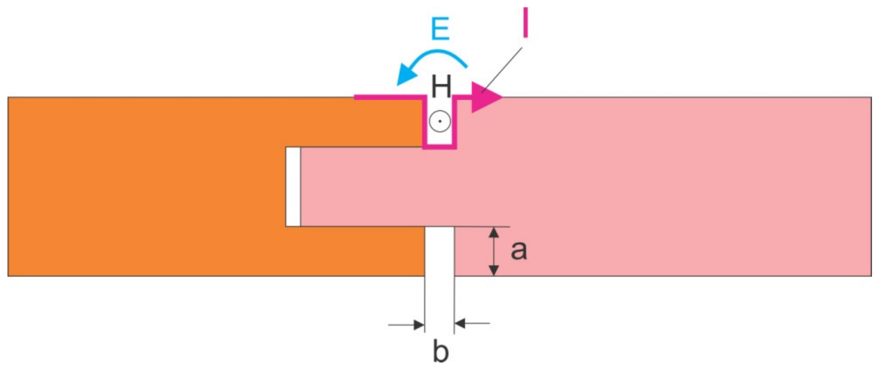
HV bias insulator in 3-1/8’’ coaxial line







Do we need a good contact of inner conductor?



$I = (2P/Z_{line})^{1/2}$ $H = I/(2\pi R)$ $U \approx \omega abH\mu_0$

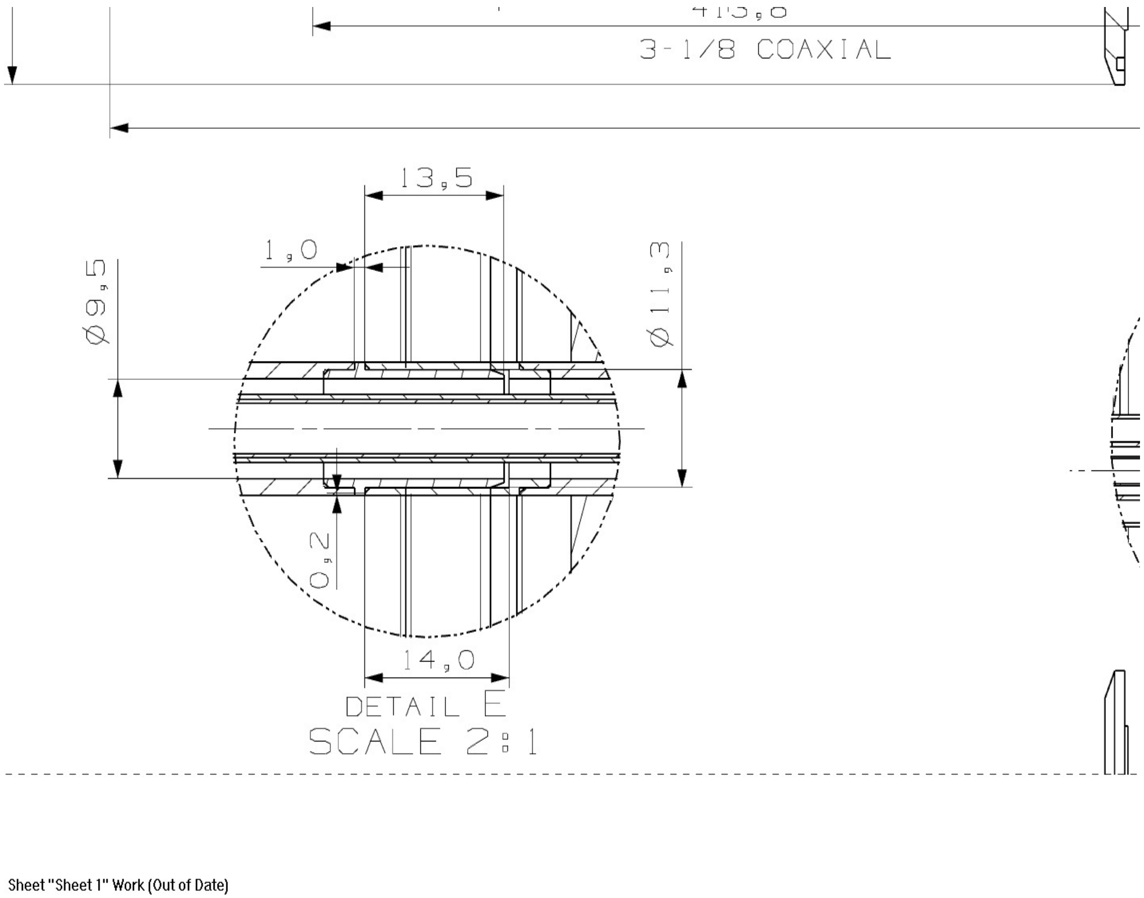
$E \approx U/b = \omega aH\mu_0 = \omega aI\mu_0 /(2\pi R) = \omega a(2P/Z_{line})^{1/2} \mu_0 /(2\pi R) = aZ_0(2P/Z_{line})^{1/2} /(\lambda R)$

$a = 1.5mm$ $E(6kW) \approx 1kV/m$ $E(30kW) \approx 2.3kV/m$

Z_{slot} (a = 1.5mm, b =1mm) ≈ 0.1 Ohm

Slot is acceptable with good ohmic contact .

Do we need a good ohmic contact ?



L = 13.5mm

R = 6.3 mm

G = 0.05mm

C = 95 pF

Z (325MHz) = 5 Ohm

Z_{Line} = 105 Ohm   Reflection ~ 0.025 (SWR ~ 1.05)

E in the gap: 6kW -> ~11 kV/cm, 30 kW -> ~24 kV/cm

Conclusion: should be no problem with inner conductor contact